MANCHESTER SCIENCE LECTURES

FOR THE PEOPLE.

MANCHESTER SCIENCE LECTURES FOR THE PEOPLE.

EIGHTH SERIES, 1876-7.

BY

PROFESSOR ROSCOE, F.R.S., PROFESSOR WILLIAMSON, F.R.S.,
and J. N. LOCKYER, F.R.S.

WITH ILLUSTRATIONS.

London:
MACMILLAN AND CO.
1877.

LONDON:

R. CLAY, SONS, AND TAYLOR, PRINTERS,

BREAD STREET HILL,

QUEEN VICTORIA STREET.

CONTENTS.

LECTURE I.

LECTURE II.

LECTURE III.

MANCHESTER SCIENCE LECTURES

FOR THE PEOPLE.

MANCHESTER SCIENCE LECTURES FOR THE PEOPLE.

EIGHTH SERIES. WINTER SESSION, 1876.

WHAT THE EARTH IS COMPOSED OF.

BY PROFESSOR ROSCOE, F.R.S.

LECTURE I.

THE question as to the composition of the terrestrial matter, or what the earth is composed of, is one which has interested men from very early times; but it is also one the solution of which has only been even partially found within a comparatively recent period. The ideas of the ancients on this subject were vague and unsatisfactory; and it is difficult for us at the present day, when our knowledge, so far as it goes, is clear and precise, to put ourselves in the position of those who lived in past ages, or clearly to see the difficulties which those great minds had to encounter who broke through the thraldom of the Aristotelian philosophy, and prepared the way for truer views of the constitution of the earth upon which we live. From remote years, throughout the dark ages, and even down to recent times, the prestige of Aristotle altogether prevented the establishment of anything like a true view of the great phenomena of Nature. The doctrine of the existence of the four elemental states of matter—fire, air, water, earth—was generally accepted; and the possibility, nay, the proved fact, of the conversion of one kind of substance into another kind, and especially the "transmutation,"

as it was termed, of the metals, was universally acknowledged; so that the strivings of the alchemists to obtain the "philosopher's stone"—which should enable them to convert the base into the noble metals—followed as a matter of course. Next came the assumption of the existence of three principles, of which the material universe was alleged to be composed, namely, mercury, salt, and spirit, which, "mingle as mingle may," were thought, somehow or other, to produce all the different forms of matter which we see around us.

The man who, more than any other, stands conspicuous as having first distinctly opposed the prevailing views respecting the essential constitution of matter, and to whom we are indebted for the overthrow of the Aristotelian as well as the Paracelsian philosophy, is the Hon. Robert Boyle, who was born in 1627 and died in 1691. Robert Boyle was a very extraordinary man. He left behind him an extensive series of works, in which we find not only the description of a large number of important physical experiments and discoveries, but treatises upon almost every other branch of inquiry, including even theology. In his curious and interesting chapter entitled *The Sceptical Chemist*, published in 1661, he upholds the view that it is not possible, as had hitherto been supposed, to state at once the exact number of the principles or essential constituents of matter; but that, on the contrary, all those forms of matter which were not themselves capable of further separation must be regarded as simple or elementary bodies. Thus, in his introduction to the *Sceptical Chemist; or, Critical Chemico-Physical Doubts and Paradoxes touching the Experiment, whereby Vulgar Chemists are wont to endeavour to evince their Salt, Sulphur, and Mercury to be the true Principles of Things*, he uses the following expression:—

"It may as yet be doubted whether or no there be any determined number of elements; or, if you please, whether or no all compound bodies do consist of the same number of elementary ingredients or material principles."

Boyle was the first to point out the great fact—which is now the corner-stone of our science of chemistry—that a grand distinction must be drawn between compound and elementary bodies. He held, as indeed all chemists do at the present day, that chemical combination consists of an approximation of the smallest particles of matter, and that decomposition takes place when a third body is present capable of exerting on the particles of the one element a greater attraction than is possessed by the particles of the other element with which it is combined. We

have in the works of Robert Boyle, then, the first instance of the recognition of the important fact in the world of science, that there is an essential distinction between substances which the chemist is able to split up into different bodies, and those substances which the chemist is unable to divide thus; and to this latter class is given the name of *chemical elements*. I will endeavour to elucidate this difference in the essential properties of matter by an historical illustration. The year before last Professor Thorpe gave us a lecture in this hall upon the life and labours of Joseph Priestley. Those who were present on that occasion will remember that Professor Thorpe pointed out how Priestley discovered oxygen on the 1st August, 1774. They will remember that Priestley took some of this red powder, which he termed calx of mercury, and found that when it was heated by the rays of the sun it underwent a peculiar change. We cannot heat the powder at this moment by the direct rays of the sun, but we will do so by indirect solar rays, for the heat of this gas-lamp is in fact nothing but solar heat derived by a round-about process. If I heat this red powder, as Priestley did, we find that it disappears, and that whilst the red particles disappear, certain bright globules become visible on the side of the tube; and these globules prove to be shining metallic liquid, mercury, or quicksilver. Moreover, a gas is given off which has the power of re-igniting this bit of red-hot chip of wood, as you may see, when I plunge the red-hot wood into the colourless gas contained in the tube. Here then we have a very distinct and remarkable change taking place, a change which no one could foresee, and which was not observed until about the year 1774, when Priestley made the experiment you have seen, bringing about a creation of two distinct things out of this red powder, namely, the bright metallic liquid mercury which you see here; and the colourless oxygen which we have in this globe.

The news of this discovery of Priestley's was at once conveyed to Paris, and became known to the French chemist, Lavoisier, and he then made an experiment which is of great historical interest, as not only illustrating the point upon which we are engaged, but at the same time proving the fact that the air is not a simple or elementary substance, but contains two different gases, viz., oxygen and nitrogen. For this purpose he introduced into this globular retort (Fig. 1.), the long neck of which was bent down as you see, about four ounces of pure mercury or quicksilver, and he measured carefully the exact volume of air

contained in the retort and in the bell-jar, the side of which was marked with a graduated scale. By means of a furnace he heated the mercury nearly to its boiling point. The total volume of air before he began his experiment, was exactly fifty cubic inches, at a temperature of ten degrees, and the barometer at twenty-eight inches. At first no apparent change was brought about by the action of the heat, but after a while, little red specks began to appear upon the surface of the mercury, and these specks grew larger and more numerous as the heat continued. At last, after heating it for twelve days and twelve nights, no further increase in the number and size of these

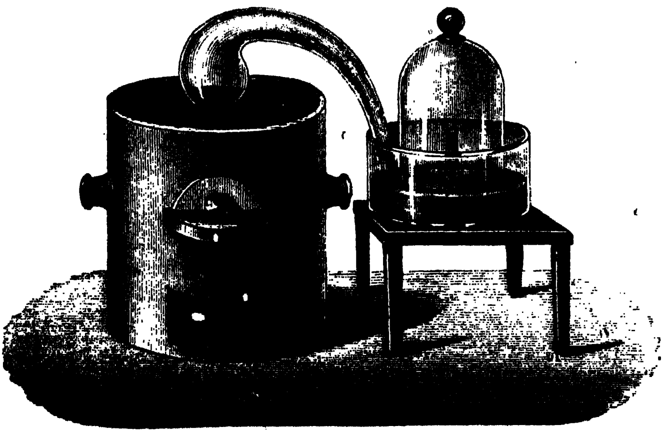


FIG. 1.

red specks was observed, and so Lavoisier allowed the whole apparatus to cool down again to ten degrees. He then once more measured the volume of air, and he found that instead of having fifty cubic inches of residual air, the volume was reduced to between forty-two and forty-three cubic inches; so that it appeared that from seven to eight cubic inches of air had disappeared. Lavoisier next took his apparatus to pieces, and collected carefully all the red powder, which he found to weigh exactly forty-five grains. The next part of his experiment is illustrated. He took the forty-five grains and placed them in the small tube-retort (Fig. 2), and proceeded to heat the powder by means of a lamp, having a gas delivery tube so arranged that

he could collect and measure any gas which might be given off in a graduated cylinder. After he had heated these forty five grains of powder for some time, he found that a gas made its appearance, whilst at the same time mercury was deposited on the sides of the tube. When the operation was completed, and the whole of the powder had undergone this change, Lavoisier observed that between seven and eight cubic inches of a peculiar gas had come over into his cylinder, and this gas had the property of re-igniting a red hot splinter of wood; it was, in fact, oxygen gas, or "vital air" as it was then termed, which Priestley had previously discovered.

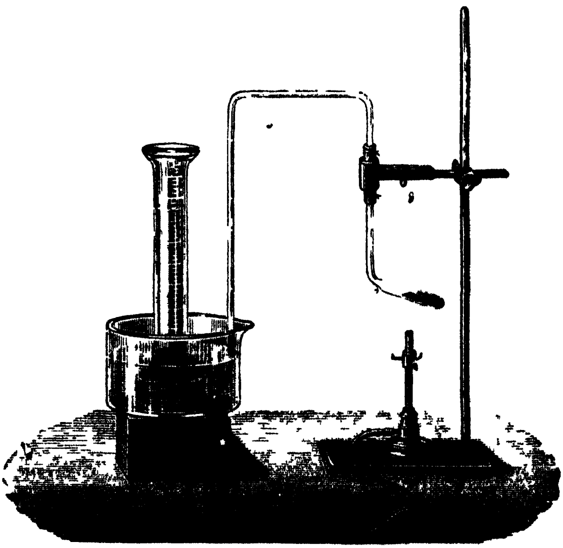


FIG. 2

I will now give you another illustration of the possibility of splitting up some kinds of matter into different constituents. In the year 1783, some time, as you will observe, after the discovery of oxygen gas, a man of whom you have also heard, and whose discoveries were pointed out to you last year by Dr. Thorpe, I mean the great Henry Cavendish, proved that water is not an elementary substance, but that it may be produced by bringing

together two quite different kinds of matter, that is, these two colourless gases, which we term oxygen and hydrogen. Cavendish showed that when these two gases, the first of which was then termed dephlogisticated air, and the latter inflammable air, were united in the right proportion, namely, one volume of oxygen and two volumes of hydrogen, they produced water, and nothing besides. In the year 1800, some seventeen years after this discovery by Cavendish, the action of electricity upon water was discovered by Nicholson and Carlisle; and it was found that by sending a current of electricity through acidulated water, we can actually separate the constituent parts of water, and obtain an evolution of the two permanent

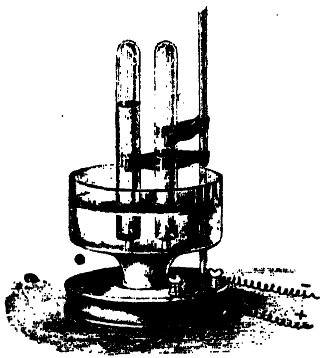


FIG. 3.

gases. In order to illustrate this fact, I will pass a current of electricity through some acidulated water, and the moment I make the contact of the wires, you see on the screen a rapid ebullition of the water, but in which the bubbles do not consist of steam, but of permanent oxygen and hydrogen gases. From this we learn that water is composed of these two gases. Next I have to show you how we can ascertain the exact quantity of the two gases necessary to be combined to form water. Instead of allowing the bubbles to escape, as in the previous experiment, I will collect from the one wire the oxygen, and from the other the hydrogen, gas. You see now that bubbles are rising from both wires, and you will notice in a short time that the two gases will collect in their separate tubes; you will likewise observe

(Fig. 3) that the volume of gas in one tube is larger than the other; and when we make the experiment with care, we find that the volume in the one case is exactly double that in the other, the oxygen being always exactly half the volume of the hydrogen. Here then we have another instance that such an apparently simple substance as water can be split up into two totally different substances—oxygen and hydrogen.

As a third instance of the decomposition of substances into two or more essentially different bodies, I may take this white salt, called sugar of lead, and I show you that it contains the well-known metal lead. This metal I can obtain from the white powder by a similar kind of process to that which I adopted for the extraction of the mercury from Priestley's red calx, only that in place of heat I shall employ electricity for the purpose of separating out the lead. You now see that when we make the contact we obtain on the screen a beautiful crystallization of metallic lead. You observe that the crystals are beginning to grow, and are throwing out their arborescent shoots over the screen. From the other wire we have the evolution of bubbles which if collected would turn out to consist of oxygen gas. In the time of Lavoisier, only seventeen elementary substances were known, and these seventeen bodies were the bricks out of which the chemistry of that time had to be built. These seventeen elementary bodies were divided into three classes: we have:—

ELEMENTS KNOWN TO LAVOISIER.

CLASS I. THE NON-METALS,	CLASS II. THE TRUE METALS,	CLASS III. THE SEMI-METALS,
Oxygen, or vital air.	Gold.	Arsenic.
Hydrogen, or inflammable air.	Silver.	Antimony.
Nitrogen.	Copper.	Bismuth.
Chlorine.	Lead.	Zinc.
Carbon.	Iron.	Cobalt.
	Tin.	Nickel.

Since the time of Lavoisier, thanks to the labours of several generations of chemists, we have now become acquainted with sixty-four elementary substances, existing in varying proportions in the air, the water, and the solid crust of the earth. Here is a list of these elements, some of which are widely distributed;

others are marked "common and useful;" while a long list at the bottom is marked "rare elements":—

TABLE OF THE ELEMENTS KNOWN AT THE PRESENT TIME.

MOST WIDELY DISTRIBUTED.

Aluminium.	*Hydrogen.	Oxygen.
*Bromine.	*Iodine.	*Phosphorus.
Calcium.	Iron.	Potassium.
*Carbon.	Magnesium.	*Silicon.
*Chlorine.	Manganese.	Sodium.
*Fluorine.	*Nitrogen.	*Sulphur.

COMMON AND USEFUL.

Antimony.	Copper.	Silver.
Arsenic.	Gold.	Strontium.
Barium.	Lead.	Tin
Bismuth.	Mercury.	Tungsten.
Boron.	Nickel.	Uranium.
Chromium.	Platinum.	Zinc.
Cobalt.		

RARE.

Cadmium.	Lanthanum.	*Selenium.
Cæsium.	Lithium.	Tantalum.
Cerium.	Molybdenum.	*Tellurium.
Didymium.	Niobium.	Thallium.
Erbium.	Osmium.	Thorium.
Gallium.	Palladium.	Titanium.
Glucinum.	Rhodium.	Vanadium.
Indium.	Rubidium.	Yttrium.
Iridium.	Ruthenium.	Zirconium.

Many of the substances named in the third division are but slightly known, and have been experimented on by only a few chemists, and most of these have as yet not been applied to any useful purposes in the arts or manufactures; still we cannot tell what a day may bring forth, and even the rarest of these elements may at any time prove to be a useful and important body in ways not dreamt of before.

The next important fact which I wish to bring before you is the fixedness of the composition of chemical compounds. How would it be possible to have a science of chemistry if the composition of chemical substances varied from time to time? We know that if we once make an accurate determination of the quantity of lead which can be got out of a certain weight of

this white sugar of lead, or of the mercury which we can obtain from this red calx, we need not trouble ourselves to make a second determination. By one accurate experiment we can be certain as to the result, for experience has shown us that the same chemical compound always contains its constituent elements in the same unvarying proportion; and this important conclusion is one which can be arrived at by experiment alone.

It is only by experiment, or by putting questions to nature, that she divulges her choicest secrets. Of all the means which have assisted chemists in arriving at these conclusions, the help afforded by the *balance* is the most important. The first man who employed the balance for the purposes of research appears to have been Joseph Black, professor of chemistry, first in Glasgow and then in Edinburgh. Black's balance is now to be seen in the valuable and interesting exhibition of scientific instruments at South Kensington; and although Black's instrument was not a delicate one, simply consisting of a rough pair of scales, nevertheless, with it he made investigations and determinations which have an undying interest.[1] After Black came Lavoisier, and it is generally stated that Lavoisier was the first to introduce the balance. This, however, was clearly not the case; for although he employed the balance largely, we are indebted to Black for its first introduction. In writing to Black in 1790, Lavoisier acknowledges the claims of the Scotch chemist in the following remarkable words:—

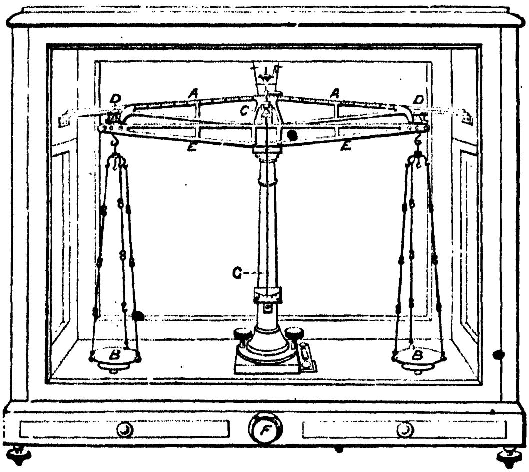
"Il est bien juste, Monsieur, que vous soyez un des premiers informés des progrès qui se font dans une carrière que vous avez ouverte, et dans laquelle nous nous regardons tous comme vos disciples."

This is a clear recognition of Black's claim to the merit of discovering the method of investigation which Lavoisier afterwards employed.

From what I have said, the necessity for experimentation—in order that we should attain a knowledge of the chemical properties of the substances of which the earth is made up—will be evident to you all. I may illustrate this in a very simple way. Suppose, for instance, that we have here—as is indeed the case —a series of jars filled with colourless, invisible gas, which, so far as we can tell, by merely looking at them seems to be of one kind. If, however, we interrogate Nature, that is, if we

[1] *Experiments upon Magnesia, Albu, Quicklime, and other Alkaline Substances.* Edinburgh, 1755.

make an experiment, as to the nature of the gas contained in these jars, we shall find that, although apparently the same, these gases are in fact very different substances. If I take this taper and insert it into the jars, this difference will soon become visible. When I dip the taper into the first jar, we do not notice any apparent change, for the flame of the candle burns much as it did before. If I put the taper into the next bottle there is a distinct change, for the taper is at once extinguished. When I place the extinguished taper, having, however, its wick still red-hot, into the third jar, you will see another change, for



Here you have (FIG. 4) a figure of a chemical balance.

the taper is instantly rekindled, indicating by the brilliancy of the combustion the existence of a totally different gas. Again; I will drop the burning taper into the fourth jar, and you see that the colourless gas itself takes fire and burns, although it extinguishes the flame of the candle. I can show you in other ways, by weight as well as by sight, that these gases differ from one another. For here I can pour one gas like water from one vessel to another; whilst in another case I can pour the gas upwards, because it is lighter than air. These are properties of gases, then, which can only be learned by experiment.

Understanding, then, that bodies always have a fixed composition, let us proceed a step further, and ask ourselves whether there is such a thing possible in Nature as a loss of matter. If I take this piece of watch-spring, kindle the string tied to one end, and then plunge it into a jar filled with oxygen, you see that the watch-spring burns, and in burning it will deposit a quantity of red-hot oxide. Observe the brilliancy with which the iron is now consumed, but also notice that the white-hot molten globules which fall down indicate what has become of the watch-spring, which no longer exists as such, but instead of it we have some quantity of a brown deposit, which we know as "rust of iron." If we next take as an example of chemical change that which occurs when a common candle burns, we cannot so readily observe what becomes of the materials of the candle. That the wax and the wick, the materials of which the candle is composed, disappear is certain. The question is, have they been destroyed, or have they only undergone a change and become invisible to our eyes? By this very simple arrangement we have the means of answering this question, for we can collect all the products of the combustion of the candle, the carbonic acid and the water, and we can show that these products weigh more than the candle does, just as the iron-rust produced in our last experiment weighs more than the watch-spring did. I have here a little taper, which is placed in a tube (Fig. 5), and this tube is placed at the end of the beam of a balance, which is arranged to be in exact equilibrium. Now I am about to burn the candle, and I shall collect the products of its combustion in the white caustic soda contained in the upper part of the tube (Fig. 5), so that nothing will escape but the air which has passed through the flame in the burning of the candle. I must have a current of air passing through in order to make the candle burn, and this I obtain by allowing the water to run out of this oil can, the top of which is connected with the tube. The candle is now burning, and the question is—What has become of the wax and the wick? I want you to see that the materials of the candle, instead of having been destroyed, exist under another form—that of carbonic acid and water, which products have been laid hold of by the caustic soda and prevented from escaping. At the end of our experiment we shall find that the candle has lost half its weight, and that the other end of the balance is heavier by the oxygen of the air which the component parts of the atmosphere have taken up. You observe that this side of

the apparatus is heavier than it was before, showing that in the case of a burning candle there is no such thing as a loss of matter. And this conclusion as regards this one case of chemical change has been proved by thousands of careful experiments to apply to every other case which has come under the eyes and hands of the chemist.

Let us next consider for a moment the distribution of the elementary bodies. In the first place we find that while only

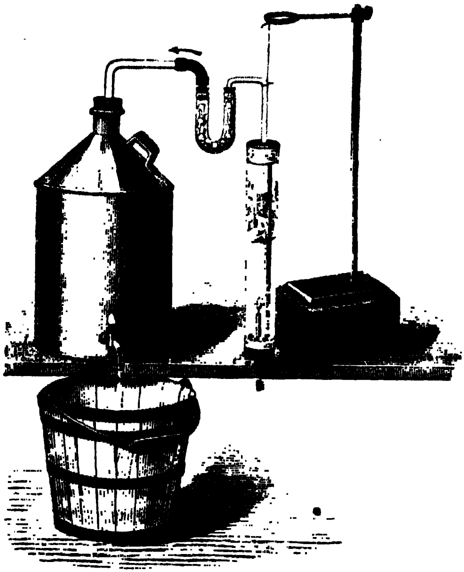


FIG. 5.

about four elements are found in the air, about thirty exist in the water of the ocean, whilst the rest are found in the solid earth. We are, however, quite unacquainted with any law regulating their distribution, but we find that certain elements are universally distributed whilst others occur most rarely. Thus, oxygen is found in almost every solid as well as in water and air, constituting (as is seen from the following table) about one-half of the solid crust of the earth.

Here you have a table giving the average composition of the solid earth's crust so far as the primary rocks are concerned. It shows that the bulk of the earth's solid body is made up of only eight elements, the remainder existing in the earth in much smaller quantity.

COMPOSITION OF THE EARTH'S SOLID CRUST IN 100 PARTS BY WEIGHT.

Oxygen	44·0 to 48·7	Calcium . . .	6·6 to 0·9
Silicon	22·8 to 36 2	Magnesium . .	2·7 to 0·1
Aluminium .	9·9 to 6·1	Sodium . . .	2·4 to 2·5
Iron	9·9 to 2.4	Potassium . . .	1·7 to 3·1

Respecting the composition of the whole mass of the earth we are as yet, as I have said, to a great extent ignorant, and a little consideration will show why this is the case. Imagine, if you please, that C (Fig. 6) represents the centre of the earth, and that the lines AC, and BC, are radii to the surface of the earth. Then the black line, AB, represents the portion of the earth's crust known to man. The greatest height to which man has ascended by means of a balloon, and the greatest depth to which he has descended by means of a mine, are included in the breadth of that dark line, so that all beyond this black line towards the centre of the earth is to us, so far as man's penetrating power is concerned, terra incognita. But although we cannot get there, yet we have means of learning something about the composition of these internal parts, because we can examine the chemical nature of the lava which is thrown up by volcanoes, and we can also examine the salts held in solution by spring water which comes from a great depth below the earth's surface.

Many of the hot deep mineral springs, such as those at Bath and Buxton, bring up to the surface various compounds and elements in a state of solution, the nature and properties of which can be examined by chemical means. But beyond these two means, we have at present no direct way of ascertaining what kind of elements or compounds exist at a great depth below the surface of the earth.

In the year 1772 a very interesting series of measurements was made in Scotland on a mountain known to many of you, called Schehallion. This mountain possesses very steep sides, and it occurred to several mathematicians, Maskelyne especially, that by making plumb-line observations on each side of this steep mountain it might be possible to determine the mean density of the earth, which might in turn guide us to a knowlege of the nature of the portions of the earth to which we

cannot get access. It was found that the plumb-lines hung on each side of the mountain were deviated a little (11″·7) out of the perpendicular by the weight of the mountain. Now if we know the size of the mountain, which can be obtained by a trigonometrical survey, and if we know the specific gravity of the rocks composing the mountain, such as this I hold in my

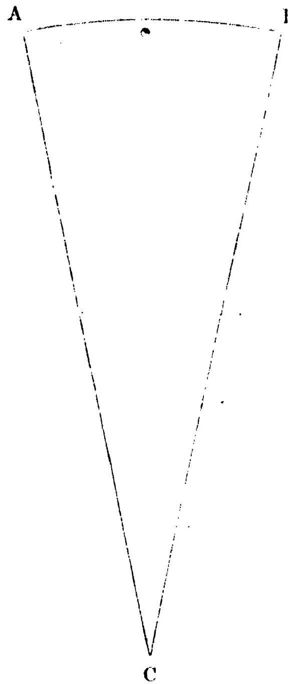


FIG. 6.

hand, and which is two and a half times heavier than water, we can discover the ratio of the attraction of the mountain to that of the earth. And then, we can get the absolute mass of the earth, and knowing its volume, we can get the mean density of the earth, that is to say, we can tell how many times the earth is heavier than an equal bulk of water. This was the first experiment made on this very interesting subject; and the

calculations of Hutton and Playfair from the observations of Maskelyne made the mean density of the earth to be 4·713, that is to say, they came to the conclusion that the earth is, roughly speaking, 4¾ times heavier than an equal bulk of water.

Afterwards, another method was employed to determine this fact, namely, by means of a torsion balance, an instrument used by Cavendish, by means of which he found that the density of the earth was 5·48, or about 5½ times heavier than water. Other observations have been made on this subject, the best of them being the result of a Commission appointed by the Government in 1838, in which the astronomer Baily was concerned. His investigations extended from October, 1838, to May, 1842, and he came to the conclusion, which we may regard as the most accurate one which has yet been obtained, that the mean density of the earth was 5·66, or rather more than 5½ times heavier than water. It is worth remembering that Newton, in his great work, the *Principia*, predicted with a most remarkable degree of accuracy, that the earth would be found to be between five and six times as heavy as its bulk of water.

You may ask—What has all this to do with the composition of the earth? Well, it has to do with it in this way: that when we descend to the greatest possible depth into the earth and bring up its solid contents, we find that the highest mean specific gravity of the rocks is 2·5, so hence the question arises—What is it that makes the earth so heavy at its centre? It cannot be all made up of granite, because even the enormous pressure of the surrounding parts would not double or treble the density of granite at the earth's centre, and yet we find that the density of the earth is between five and six. Here we come pretty nearly to the boundary of our knowledge, and at this point chemical science cannot help us further; and it is well we should see that there is here for the present a limit to our exact knowledge, and that all beyond must remain more or less conjectured until we are in possession of further experimental data.

As I shall show you in my next lecture, there are a number of elementary bodies whose specific gravity is very much greater than that of granite. Many of the metals, for instance, are much heavier than granite; and we can suppose, if we like, that the interior portions of the earth are composed of metals.

Perhaps Mr. Lockyer may continue these considerations, and he may inform you that there are other grounds for believing

that the interior of the earth may be largely composed of unoxidized and heavy metals.

Then you may ask—Is the inside of the earth fluid or solid? Even in such an apparently simple question as this we are still in some degree of doubt. You may think this is strange, because we find volcanoes throwing out lava, which is liquid rock, and because we find much other geological evidence to show that solid rocks, such as basalt and trap, have been protruded as molten masses within recent geological epochs; but it has recently been shown by Mr. Mallet that the fact of volcanoes throwing out liquid rock may not be inconsistent with the view that the earth as a whole is solid. Mr. Mallet's investigations go to prove that this liquefaction of the rocks which we observe may be produced at no very great depth from the earth's surface by the shifting and rubbing together of the rocks, owing to cracking due to the alteration of the temperature, just as boys at school rub a button on the bench until it is hot, when they often place it on to their neighbour's cheek. Applying the laws of the Mechanical Theory of Heat to this problem, Mr. Mallet believes that the friction of the rocks, caused by the secular cooling of the earth and the consequent shrinkage, is a sufficient and a satisfactory explanation of the occurrence of the high temperature of volcanic action.

Sir Wm. Thomson,[1] also, than whom no one is more capable of expressing an opinion, decides in favour of the earth's solidity. He tells us in his address to the Physical Section at Glasgow, that the conclusion concerning the solidity of the earth originally arrived at by Hopkins is borne out by a more rigorous mathematical treatment than this physicist was able to apply, so that the idea of geologists, who were in the habit of explaining underground heat, ancient upheavals, or modern volcanoes, by the existence of a comparatively thin solid shell resting on an interior liquid mass, must now be given up as untenable.

[1] See *Nature*, Sept. 14, 1876.

WHAT THE EARTH IS COMPOSED OF.

LECTURE II.

In the last lecture I described to you some of the properties of the various kinds of matter of which the earth is composed. I showed you that the various gases which occur on the earth's surface differ from one another in a very remarkable degree. I pointed out to you that some of these gases are light, whilst others are heavy; and that it is only by experiment we can arrive at a knowledge of these facts concerning the nature of terrestrial matter. I wish to illustrate these facts to you once more. We have here two gases differing from each other in specific gravity as well as in other properties; and I think I can make this evident to you by a simple experiment. In this long cylinder, which is apparently filled by a homogeneous colourless gas, we have in fact two gases, one of them heavier than the other. If I plunge this red-hot wick of the taper into the gas at the top of the cylinder, you will observe that it will be rekindled; but that it is extinguished when I push it lower down; whilst it is again ignited if I again raise it into the upper part of the cylinder. Now the gases which compose our atmosphere also differ in specific gravity. Oxygen is somewhat heavier than nitrogen, their weights being in the proportion of the numbers 8 and 7 respectively. Our great townsman, John Dalton, whose discoveries were brought before you in a lecture the season before last, came to the conclusion that in consequence of this difference in specific gravity of the constituent gases of the atmosphere, we should find, in the upper portions of the atmosphere there was a larger quantity of the lighter gas (nitrogen), and in the lower portions a larger quantity of the heavier gas (oxygen). But this was found by experiment not to be the case. It was proved that the air

collected at a great height and that collected at the surface of the earth at the same time, exhibited exactly the same proportions between their constituent parts. This fact we explain by the circumstance that the winds move the gases of the atmosphere constantly one among another. Moreover, we know that gases possess the property of diffusion, by virtue of which the particles of one have a tendency to diffuse amongst or interpenetrate those of another gas, thus rendering the atmosphere throughout of one constant composition, so far as regards these two principal elements, nitrogen and oxygen.

In like manner, liquid substances differ from one another in their weight. We know very well that oil will swim on the top of water. And many experiments can be made to illustrate this fact, that liquids differ from one another in their relative weights. In the following table you find the weight of some of the most common liquids compared with that of the same bulk of water taken as the unit, and these relative weights are termed the specific gravity of the liquids.

Table of the Specific Gravity of Liquids.

Water	1·00
Mercury	13·598
Sulphuric Acid	1·841
Nitric Acid	1·510
Hydrochloric Acid	1·240
Sea Water	1·026
Absolute Alchohol	0·803
Ether	0·723

In like manner solids differ widely from one another in specific gravity.

On the next page you have a table containing the specific gravities of most of the metals.

In the first column of this table you find the names of the metals, in the second a series of numbers representing how many times each metal is heavier than the same bulk of water, and that number you know is termed the specific gravity; whilst in the third column we have black bars of different lengths, exhibiting the size of the various bars of metal possessing all the same weight.

partake of the physical nature of these metallic meteorites, and that if we could obtain a portion of matter from a great depth below the earth's surface we should find it exactly corresponding in structure as well as in chemical composition with a metallic meteorite, and the existence of such interior masses of metallic iron may go far to explain the well known magnetic condition of our planet.

In the next course of lectures Mr. Lockyer will, I have no doubt, go into this subject much more fully than I am able to do, and I leave it to him to explain how the conclusion which we chemists have arrived at respecting the composition of extra-terrestrial matter from our examination of meteoric masses has been supplemented and extended by spectrum observations on the sun and fixed stars.

WHAT THE EARTH IS COMPOSED OF.

LECTURE III.

I HAVE this evening to open out to you a new chapter in the history of the chemical elements, and one which, if we can read it aright, is of great interest as well as of great importance. I have on this table three very different substances: a piece of charcoal, a piece of graphite or plumbago, and here I hold in my hand what you will be pleased to consider the largest diamond in the world. I need scarcely say that this is not a real diamond, but it is an exact model of the Koh-i-noor made of glass. Now these three substances, which, in their physical appearance and uses are so different, are, as I shall show you to-night, chemically one and the same body. Charcoal, graphite, and diamond, are, so far as their chemical properties are concerned, all composed of pure carbon.

In the two previous lectures of this course I pointed out to you some of the most important general properties or characteristics of the chemical elements taken as a whole. To-night I wish you to confine your attention to this one elementary substance—carbon—for we shall find that in considering its properties we have ample means of awakening our interest in becoming acquainted with some of the most striking phenomena of our science.

First of all, we will, if you please, take up the subject of the diamond. This beautiful bright, white, colourless substance was prized highly as a gem by the ancients, but as diamond is the hardest of known substances, the art of diamond-polishing was in olden time not understood, and diamonds could not be cut and polished until the year 1476, when Louis von Berguen first showed how this might be accomplished by means of diamond powder itself; for although the diamond is the hardest of all substances, yet, of course, we can crush it by

means of a blow on an anvil or by pounding it in a mortar, and this diamond powder, or diamond dust, is the only substance that will cut diamond. As the ancients were unaware of this means of polishing the diamond, they only prized those diamonds as gems in which the natural crystalline faces of the diamond were bright and transparent.

Here you see a drawing representing the crystalline form in which the diamond usually occurs.

The other form of crystalline carbon, viz. graphite, does not crystallize in this particular form in which the diamond occurs, but in quite another form, and thus another essential difference between these two forms of carbon becomes apparent.

The history of the diamond, so far as its chemical character is concerned, is one of great interest, and one upon which we

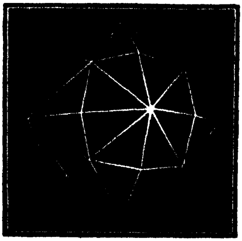


FIG. 12.

may with advantage spend a few minutes. The first hint or observation we find recorded respecting the probable chemical nature of the diamond was given to us by the immortal Newton, who from an examination of the character of the diamond, and observing its high powers of refracting or bending light, which gives to the gem its peculiar beauty and value, and observing that other substances which are known to be combustible likewise possessed this power, concludes that in all probability the diamond will ultimately be found to be a combustible body. Thus in his celebrated *Treatise on Opticks*,[1] speaking of this refractive powers of substances, Newton says: "Again, the refraction of camphire, oyl-olive, lintseed oyl, spirit of turpentine, and amber, which are fat, sulphurous, unctuous bodies, and a diamond, which probably is an

[1] London, 1704, second book, p. 75.

unctuous substance coagulated, have their refractive powers in proportion to one another as their densities, without any considerable variation." It was not, however, till the year 1694 that the academicians of Florence, under Cosmo the Third, Duke of Tuscany, made an interesting experiment, which attracted the general attention of the civilised world, on the possibility of evaporating the diamond. In Galileo's tribune at Florence you may see the identical lens, or large burning-glass, which was employed in the year I have named by the Florentine academicians for the purpose of ascertaining what effect would be produced by placing a quantity of diamonds in the rays of the sun brought to a focus by this large lens. They found to their astonishment that rubies, emeralds, and other precious stones withstood the high temperature to which they were exposed in the concentrated rays of the sun in this burning-glass, remaining quite unaltered, whilst the diamonds, the hardest of known gems, disappeared altogether. Although this fact of the evapration of the diamond was verified over and over again, chemists were still unaware of the nature of this evaporation, nor could they explain what took place when the diamond thus disappeared. It was nearly a century after this time, in January 1773, that some further experiments were made on this subject by two French philosophers, Messrs. Darcet and Rouelle. They made a variety of experiments. Placing some diamonds in a crucible inside a very hot furnace, they found that the diamonds disappeared, as they had been previously shown to do when exposed to the sun's rays in the focus of the burning-glass. They came to the conclusion that the diamond is destroyed in a short time when freely exposed to air at a temperature lower than that needed to melt silver; but that when air is excluded, the diamond turns out to be a very refractory substance, that is, it does not easily evaporate. For these same experimenters placed the diamond in a crucible, which they completely filled with powdered charcoal; and then they found that the diamond remained unaltered, although exposed for as long a period as eight days to a temperature of the highest possible kind in a porcelain furnace.

The year after these experiments were made, the great French chemist, whose name I have frequently had to mention, Lavoisier, undertook the examination of this substance, and it is worth while noticing how carefully he went to work, how he proceeded slowly from one step to another in logical

sequence, until he arrived at the true solution of the question he had undertaken to investigate; that is, until he was able to tell us exactly what happens when the diamond evaporates in the free fire, and why it did not do so when surrounded by charcoal. In the first place he evaporated the diamond by means of the burning-glass, and he observed that no visible vapour or smoke was given off, but that the diamond disappeared. He thought that perhaps the solid diamond had in some way been dissolved by the water, and that by evaporating the water which was in the lower part of the bell-jar, in which he burnt his diamond, he might obtain the constituents of the diamond in a solid form, but he found that no solid residue was left on evaporation, and thus no trace of the diamond could be found. His next experiment was that of placing a diamond in the focus of a less powerful lens than the one he had formerly used, so that the diamond was not heated to so high a temperature as before, again placing it, however, in a bell-jar over water. He then found that the diamond when not heated quite so strongly, lost only about one quarter of its weight; it did not disappear altogether, but the remarkable fact was noticed that it became covered with a black substance which Lavoisier describes as being exactly like lamp-black or soot, so that it dirtied the fingers when touched, and made a black mark upon paper. Hence Lavoisier concluded that the diamond is susceptible of being brought under certain circumstances into the condition of charcoal, so that it really belongs to the class of combustible bodies. He was however yet far from having proved his point, and he went on experimenting. He next measured the volume of air in which he was going to burn the diamond, and found it to be eight cubic inches. Then he burned the diamond in this volume of air by means of a lens, and found that the air had diminished to a volume of six cubic inches; thus showing that the air had undergone some change by the combustion of the diamond; and that two out of the eight volumes of air had disappeared. The next experiment he made was to examine the condition of the air in which the diamond had been evaporated. What changes had gone on in the air in consequence of the evaporation of the diamond? After allowing the glass in which he had burned the diamond to stand for four days, he poured clear lime-water into the jar in which the diamond had been evaporated, and he says this lime-water was at once precipitated in the same manner as if it had been brought into

contact with the gas evolved in effervescence and fermentation, or that given off in cases of metallic reduction. Here then he had got on the track of what he wanted. Hitherto the diamond had apparently disappeared, and nothing was found to account for its disappearance; but now he had found that there was something contained in the air in which the diamond was burned which was not contained in that air before.

The next step he took was to examine the white precipitate or powder which was formed, and he found that the substance thus precipitated from lime-water by the air in which the diamond had been evaporated, effervesced on treatment with acid, and evolved what was then known as *fixed air*, but which we now know as carbonic acid gas. Here, then, in his last experiment he completes his proof, showing that exactly the same effects are observed when charcoal is experimented upon instead of diamond. Lavoisier had now run his quarry to earth; he had determined exactly what it is that is formed when a diamond is burned. He has shown that a diamond when burned produces exactly the same substance that is produced when common charcoal is burned, and he, therefore, legitimately concludes that diamond is only another form of the element carbon. The reason that the diamond did not burn in the furnace when surrounded by a mass of charcoal was that the air, or rather the oxygen of the air, could not get to the diamond, because it was kept off by the charcoal, which burned instead of the diamond.

Having thus explained to you what Lavoisier did, let me try to show you the same thing. I have in this bottle a real diamond, not a very large one, but large enough for my purpose. I have in this bottle also some oxygen gas, and I am going to heat the diamond, by means of a galvanic current, in the oxygen gas until it burns, and now you see the diamond burning like a little bright star in the interior of this glass. The diamond is inclosed in a spiral of platinum wire, which I can heat up to whiteness; the wire will then heat the diamond round which it is wrapped, up to the point of ignition. I then take away the heat of the battery and leave the diamond to burn. You will next observe that when the diamond is burned, the clear lime water, which is now perfectly clear and colourless and transparent, will become turbid, exactly as in the case of burning graphite and common charcoal.

I will next burn a bit of graphite, or plumbago. Graphite

is a form of carbon found in large quantities in Cumberland, Siberia, Ceylon, and other places, and is used, as you know, for making black-lead pencils. A much higher temperature is required for the purpose of igniting graphite than diamond; but here, as you see, the clear lime-water has become turbid. Next I will burn a bit of charcoal in the third jar, and the same effect is produced upon the clear lime-water. In other words, in these three different substances, we have one and the same elementary body, carbon, so that by their combustion in oxygen, the same gas, namely, carbonic acid gas, is formed.

From the experiments of Lavoisier, although they completely decided the question as to the diamond consisting mainly of carbon, it did not follow that carbon was the sole constituent. Indeed, for many years after these experiments, it was supposed that the colourless gas, hydrogen, is combined with the carbon in the diamond, and this, it was thought, might account in some degree for the difference in the physical properties of the diamond and other forms of carbon. Further experiments were needed to elucidate this point. In the year 1814, Sir Humphry Davy read a paper before the Royal Society, describing the effects which were produced when a diamond was very carefully burned in perfectly dry oxygen gas. In this case no trace of moisture was found, which must have been produced if the diamond had contained hydrogen, whereas in similar experiments made with charcoal, instead of diamond, a production of moisture was invariably observed. But Davy was not satisfied until he had taken some of the chalk obtained from the gas in which diamond had been burnt, and had actually prepared from it black carbon or soot. This he did by heating the white carbonate of lime or chalk with the metal potassium, which then took away the oxygen from the chalk and liberated the carbon in the form of soot. Thus he was able to actually get some lamp-black from the carbonic acid produced by the combustion of the diamond, and this, when strewed in a flame, took fire and burned like common charcoal, so that charcoal was got by Davy from the diamond itself.

I need scarcely say that the diamond has never yet been artificially made; although we should not be surprised some day to hear that such was the case, and that the chemist had been able to change one form of carbon into another, or to prepare the diamond. We do not know at all how the diamond has been made, and all attempts—and they have been many

—to convert the black form of carbon into the colourless crystalline form have hitherto failed.

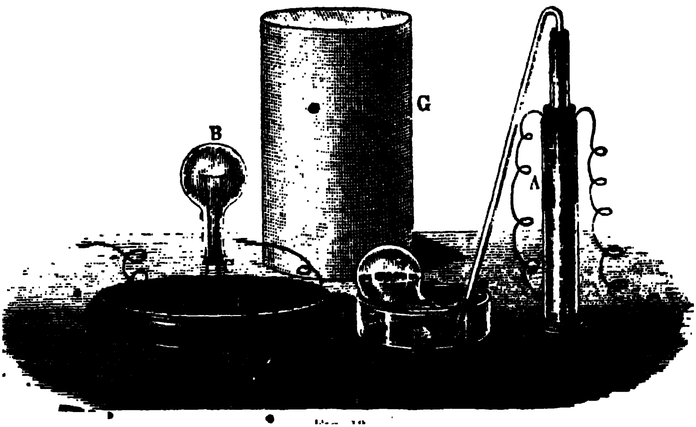
In many other respects carbon is one of the most interesting of the elementary bodies. In the first place, if we can imagine carbon struck off the list of the elements, if the earth did not contain any carbon, then we must also imagine the world without any organised beings, without animals, without plants, destitute in fact of all forms of vegetation, from the simplest germs to the tree which towers above our heads, destitute also of all forms of animal life, from the most elementary protoplasmic forms, to the most complicated arrangements of nervous and muscular existence. Carbon is, then, an essential element of plants and animals.

That carbon occurs in colourless gases, liquids and solids, I may show you in two or three ways. If I mix this colourless olefiant gas with chlorine gas, and then apply a light, you will see a large black cloud arise, indicating the presence in this colourless gas of carbon which can then be rendered apparent in the solid form. I will next show you that this colourless liquid contains carbon. This is a product of vegetable life, a liquid which we know as turpentine, and if I pour a few drops of this colourless turpentine upon this paper and then plunge it into a jar of chlorine, you see that we get the evolution of light and heat, for the turpentine bursts into a flame and causes a dense smoke, proving that the turpentine contains carbon. We all know that vegetable and animal bodies contain carbon, for when they are partially burnt they are said to be charred. I may show you that white sugar contains large quantities of this black carbon. I have only to pour a little hot water on the sugar to make a syrup of sugar, and then pour on it some sulphuric acid, when we shall see the sugar is converted into a large mass of black charcoal.

Not only because carbon forms the greater part of the structure of all vegetable and animal existence is it important, but it is likewise interesting to the chemist, because, beyond all the other elementary bodies, carbon possesses the power of forming a great variety of compounds; so that the chemist is acquainted with a larger number of carbon compounds than he is of compounds from all the other sixty-three elementary bodies put together.

It is easy to understand that in the progress of science that portion which we may call the destructive portion will be the first to be developed. It is very much more easy to destroy than it is

to build up in matters of science as well as in matters appertaining to everyday life. Consequently, the destructive powers of the chemist were first brought to bear upon matter. It is easy, as I have shown you, to destroy this white powder, sugar, but it is not so easy to build it up again. It is only quite recently that what I may term the destructive chemistry has given place to the constructive. It is especially with regard to carbon compounds that this constructive chemistry has developed the most interesting results. In other words, the constructive chemistry of the inorganic or mineral portion of our science is simpler, and therefore easier and less interesting, than the constructive chemistry of the organic portion, or that



which consists mainly of the chemistry of the carbon compounds. I will illustrate this to you by two simple experiments. I have here a little glass bulb, B, Fig. 13, which is filled with oxygen and hydrogen, obtained by the decomposition of acidified water contained by means of the voltameter (A). There is little difficulty in getting these two gases to combine to form water; all I have to do is to pass an electric spark through the gases contained in the bulb, when you hear a loud explosion, which indicates that the particles of oxygen and hydrogen have united together, a drop of water being the result, so that our inorganic constructive chemistry has received an illustration.

Here, again, I have in this second bulb two other gases, termed chlorine and hydrogen, and I hope to obtain the combination of these two gases, not by passing an electric spark through them, as in the former instance, but by exposing them to a bright light by burning near the bulb this piece of magnesium wire. Here we have in a very simple way brought about a combination of the particles of chlorine and hydrogen.

But suppose we now, on the other hand, take a substance such as alcohol—which we know contains carbon, hydrogen, and oxygen,—can we put together the components of alcohol as readily as we can those of water or of hydrochloric acid? Alcohol, we know, is produced by the very complicated process

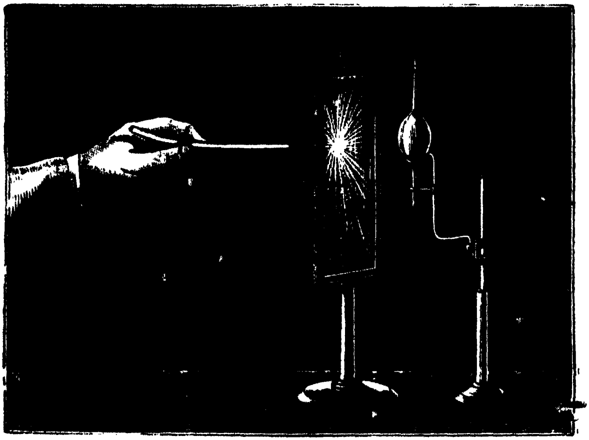


FIG. 14.

of fermentation, and for a long time this was the only method known by which alcohol could be obtained. It is only quite recently that chemists, after years of toil and of preliminary work, have at last arrived at the point of being able to build up alcohol artificially by the union of its constituent elements. Now, however, this can be accomplished not only in the case of alcohol, but in that of a variety of organic compounds. The most interesting examples of constructive chemistry are to be found in that large class of compounds which are the peculiar products of the complex series of phenomena which we designate by the term life. Certain of these substances

have been long known as characteristic products of the animal world, whilst others are always formed by the processes of vegetable life. Now it was for a long time believed that these peculiar substances are produced within the animal or vegetable body according to laws and by actions which man could not artificially imitate.

When, however, in the year 1828, Wöhler first artificially prepared urea, a body especially typical of animal life, from its inorganic sources, carbon, oxygen, hydrogen, and nitrogen, the supposed barrier between purely mineral and animal or vegetable bodies was at once broken down; and since that time so many instances have taken place of the artificial production of naturally occurring products, that all chemists now acknowledge the truth of Liebig's remarkable prediction in 1838, in which he says—"From these researches the philosophy of chemistry must draw the conclusion that the synthesis of all *organic* compounds, which are not *organized*, must be looked upon not merely as probable, but as certain of ultimate achievement. Sugar, salicin, morphine, will be artificially prepared. As yet we are ignorant of the road by which this end is to be reached, since the proximate constituents required for building up these substances are not yet known to us; but these the progress of science cannot fail to reveal."

I will illustrate this to you by showing you on the screen, with Mr. Harrison's kind assistance, the crystallisation of this body, urea, first artificially produced by Wöhler. You now see these needle-shaped crystals shooting over the screen, and observe the lovely colours which they exhibit when examined by means of the beam of polarised light. Here is another body, tartaric acid, a well-known vegetable product, which has been artificially prepared. As you are aware, this substance occurs in the juice of the grape, being deposited in the form of cream of tartar whenever new wine is allowed to stand. This was formerly the only known mode of preparing tartaric acid; but now it may be made artificially, and from carbon, oxygen, and hydrogen we can build up these magnificent crystals of tartaric acid. I might illustrate still farther this same constructive power of modern chemistry with many striking examples, but one or two more must suffice. Here are two strongly smelling oils which all who are within reach of their odour at once recognise as the oil of black mustard-seed, and the oil of garlic. These substances have, of course, long been known as the peculiar products of two plants.

Now we can prepare both these oils artificially, and by this I do not mean that the artificial oils so nearly resemble the natural oils that they can be used for the same purposes, for flavouring food, for example, but that the artificial and the natural oils are identically the same substances, possessing absolutely identical properties, and being indistinguishable by any known means.

One other interesting example of the artificial production of substances I must mention, namely, the artificial preparation of alizarine, the well-known colouring matter of madder. This substance has long been used for producing the fine purple and pink colours so characteristic of Manchester printed goods.

A few years ago this colouring matter was exclusively obtained from the madder root; but now this same colouring principle is made extensively by artificial means from gas tar, and the culture of the madder root may now be said to have come to an end. I have here small quantities of these natural and artificial substances, and I will show you that the colours of these two solutions are absolutely identical. Here then you have one of the latest triumphs of the chemist's constructive skill, which resulted in the creation of a new industry and the complete reorganisation of one of the staple manufactures of the country, all arising out of what appeared to many to be a trivial discovery of two German chemists.

In all these instances of constructive chemistry we have to do either with chemical compounds capable of taking regular geometric forms, to which we give the name of crystals, or else with liquids, such as alcohol and the oils already named.

There is, however, a form of matter derived from animal and vegetable sources which we have not yet been able to prepare, or in other words, there is a point beyond which at present we cannot go; I was about to say—a point beyond which we never shall go; but I will not say that, because it may savour of dogmatism, and this is a condition of mind which a man of science must do his best to avoid. So that although we cannot see at present the possibility of the artificial formation of the kind of matter to which I refer, I take it that he is a bold man who says that such artificial production is for ever impossible.

I will now show you some of this *organised* as opposed to *organic* material, the production of which by artificial means is now impossible. Here on the screen you have some of these curious forms, characteristic of life, with which chemists

have but little to do, and which I rather think they feel somewhat relieved to hand over to their brothers the biologists, who can tell us about their growth and their form, but who, if I am rightly informed, do not know much more about their real structure or their intimate nature than the chemists themselves. These round masses which you see on the screen are nothing else than grains of potato-starch. If you take a potato and grind it fine, and then wash away all the cellulose or fibrinous matter, you will have what is known as potato-starch left behind. It is a beautiful white powder, and if you take the least quantity of this potato-starch on the end of a pin, and bring it under the microscope, and examine it with a high power, this is what you will see. Now here we come to

FIG. 15.

something totally different from anything we have had to do with before. Here we see something which has a peculiar structure, totally distinct from that exhibited in crystalline matter. These granules have a distinctly *organised* structure, and are of various sizes in different kinds of starch. Here is a picture of the grains of wheaten-starch. The diameter of the potato-starch granule is 0·185 mm., whilst that of the wheaten-starch granule is only 0·050 mm.

Similar organised globules or corpuscles are seen floating in the blood of all the higher animals, and these are produced by life alone.

And now, having thus brought you to the confines of the

vast subject of life and organisation, I must conclude with the hope that the short and imperfect reply which I have been able to give you to the question—What is the earth composed of?—will lead some of you to attempt to answer the question

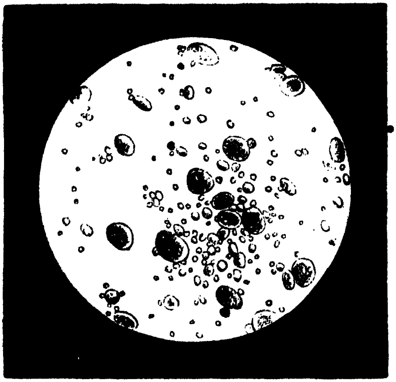


FIG. 16.

more completely for yourselves, and thus induce you to begin in good earnest the study of nature, not only as being a never-ending source of delight, but also as the best possible means of clearing our minds from the cobwebs which too often obscure our thoughts and dim our recognition of the truth.

MANCHESTER SCIENCE LECTURES FOR THE PEOPLE.

EIGHTH SERIES. WINTER SESSION, 1876.

THE SUCCESSION OF LIFE ON THE EARTH.

BY PROFESSOR W. C. WILLIAMSON, F.R.S.

LECTURE I.

WHEN this course of lectures was arranged, it was thought desirable that you should have brought before you, in a brief but connected series, a general idea of what may be called the Cosmos,—the universe; and accordingly, arrangements were made, that our friend Mr. Lockyer should tell you about the Heavens, that Dr. Roscoe should discourse to you of the Earth, and that I should follow suit, in giving you a sketch of the history of Life upon the Earth. This then is the task that has been imposed upon me.

If it be true, as many of our scientific friends believe, that man has had an ancient ancestry very different from that which we are now inclined to recognise, it becomes desirable that we should have some sort of idea, who and what those ancestors were. We are told that man was once not only a monkey, but that there was a time in which he existed as some yet more obscure form of the lower animal creation, and from which form he has developed to what he is now. This is the doctrine of the Evolutionists; a doctrine in which I need scarcely say there is a large amount of truth; a doctrine

that unquestionably explains much that has never been explained by any other hypothesis; but I have come to the conclusion, that though it does undoubtedly explain the origin of many of the lower as well as of the higher forms of animal life, I have never been able so to reconcile it with my knowledge of the facts as they stand, as to believe that it accounts equally well for the origin of man.

The study of the succession of animal life as it has appeared upon the earth is the study of an enormous number of isolated facts. Now isolated facts are always comparatively uninteresting. It is just in proportion as we can associate some general idea with those facts, and show that there exist points of union, links connecting them together, that they assume a new aspect, and exhibit a measure of interest they did not possess when standing alone. It is when thus viewed relatively to the doctrine of evolution, that facts concerning the origin and history of life appear to me to assume their newest and most independent interest. And it is in reference to this doctrine that I shall endeavour to expound to you the leading truths of the science. The doctrine of evolution presupposes that external influences, acting through enormously long periods of time, have altered the character, the wants, and the organisation of living things. But such changes could not be produced quickly; our own experience of what has taken place during the historic age shows us that such changes must have been slow. The crocodiles, oxen, cats, ibisses, and various other creatures that were embalmed amongst the mummies of Egypt, were animals such as still live on the earth without having undergone any change; the species are still identically what they were in the age of the Pharaohs.

In like manner, when we glance at the Assyrian sculptures, we see that the negro at the time of the Assyrian kingdom was precisely what the negro of the valley of Sennaar is still.

Here then we have proof that, in the examples in question, external influences, acting through thousands of years, have failed to make any material impression upon objects that flourish around us. If this be true, and there is no question that it is so, it follows, that we can never hope to test the doctrine of evolution by experiment. Man's life is too short to enable him to obtain the necessary results. Where then must we look for evidence? I unhesitatingly say, that it can only be derived from the rocks of which the

crust of the earth is composed. It is impossible for us to assign definite periods to the ages of these rocks; we cannot say how many thousands or millions of years slipped by whilst those rocks were accumulating; but we know that those periods must have been enormous. I doubt not, that we should be much safer in counting them by millions rather than by thousands; and it is in the rocks thus slowly accumulated, that we shall obtain satisfactory evidence of what time can do in permanently modifying organic forms of life.

But unfortunately the records which the rocks give us are imperfect, and they are so for many reasons. These rocks have accumulated, generally speaking, under the sea, just as sediments are accumulating now. Most of our dry land was under the ocean at a comparatively late period. At a period geologically recent the Alps and the Apennines, the Andes and the Indian Himalayas, were all beneath the sea. A map of Europe pointing out what was land and what was water at a very recent date, gives you altogether different outlines from those you have at the present time. Such changes in the sea-level have been going on perpetually, and the areas over which sediments, brought together by oceanic currents, were accumulating, have consequently undergone similar changes. Nor have they ceased to do so even at the present hour. At every period there were large areas of land separated by oceans, —and at each one of those periods both the sea and the land had, in all probability, their respective inhabitants; but many objects must have been living on the land that never reached the ocean; and even of the few terrestrial things that were entombed in the sea, remembering at how few spots the geologist has opened the bowels of the earth, you will see that many chances exist against the probability of such rare relics being stumbled upon by the fossil-hunter.

Let me give you an illustration of what I mean. We have for some time past been dredging the ocean in all directions; expedition after expedition has gone forth, culminating in that noble and successful one of the *Challenger*. Through these agencies the deepest parts of the sea have yielded many sub marine treasures, but has there been any one solitary instance, in the whole of these dredgings, in which a human bone has been fished up from the depths of the ocean? Not one; and yet we know that thousands of unhappy mariners are immersed for ever in that ocean each year of our existence. If then we merely trusted to what the dredge has brought up,

such results would tell us nothing of the life of man upon the earth. And so it must have been in all ages. It can only have been by fortunate combinations of circumstances that any particular deposit could give us a fair conception of what the life was, that existed upon the earth when that deposit was found.

If we examine the rocks composing what we call the crust of the globe, we discover a succession of layers arranged one upon another. The section on the screen may be taken to represent roughly a wide area, ranging from the central mountains of some continent to the sea, and such a section may approximately represent the structure of the outer portions of the earth's crust along a line hundreds, or even thousands, of miles in length. We here see that the lowest are the most ancient beds, and as we ascend from the lower to the upper strata, we arrive successively at those that are of more recent date. Of course if we merely dig into the earth at some few points, various parts of this series will be wanting; uplifted by volcanic and other causes, the rocks have frequently been tilted up on their edges, and since many of these uplifted portions have been swept away for thousands of vertical fathoms of thickness, by what we call denudation, it follows that many of the more modern rocks, though once existing at such spots, may have disappeared. We also find from observation that some of the more ancient rocks—as for instance those that form the mountain peaks of Snowdon and parts of Westmoreland—have not probably been entirely immersed under the sea for thousands, if not millions of years. And hence, while more recent deposits were accumulating in other parts even of the area now occupied by our own island, those particular parts may possibly never have been in such a position in relation to the sea as to enable them to receive a covering of the newer deposits. Thus you see, that, at many spots, we may fail to find the more modern strata, partly because they never accumulated at those spots, or after having accumulated they may have been swept away again by those vast denuding influences which have done so much to alter the physical structure of the surface of the globe. Nevertheless, if we begin on the south-eastern coast of England, and travel towards Snowdon, we shall cross the uplifted vertical sections or "outcrops" of most of the known rocks, beginning with the modern ones at the mouth of the Thames, passing successively the Chalk-hills of Hertfordshire, the Oolitic lime-

stones of Northampton, the Red sandstones and Coal bearing strata of Stafford, until we finally reach the ancient slates of Snowdon and the Welsh borderland. Now you know very well that if a bricklayer begins to build a wall, he does not commence by hanging his top layer in mid air, and then building downwards; he puts his first layer of bricks on the solid ground, where he can obtain a good foundation, and then proceeds to build upwards upon this foundation.

And as a general rule we may safely affirm that this has been the case with the rocks of the section before you, as well as of this other one which shows the approximate relative thicknesses of the various layers that form the crust of the globe. At its base we have a series of strata only found in America—the Laurentian rocks, named from the river St. Laurence—near whose shores they are at least 30,000 feet in thickness. Above these is another series of American rocks, which possibly are also to be found in the Hebrides—these are the Huronian beds, probably 18,000 feet thick.

Then we come to some of our own Welsh and Westmoreland mountains, where we find the Cambrian strata, which add 15,000 feet more. Yet higher we have the Silurian and other Welsh and Westmoreland rocks, 32,000 feet thick. Others, known as the Devonian beds, still higher, are from 10,000 to 14,000 feet. It is unnecessary to follow the section to its top. Enough has been said to show what an enormous mass of rock we have to account for; and yet every particle of that mass has been slowly accumulated by agencies which, depositing atom after atom, continued their action through incalculable periods. When you observe how slowly such accumulations progress at the present time—and we have no other standard whereby we can judge of their rate of progress in past ages—we are driven to the conclusion that this pile of strata represents periods which the human mind can scarcely conceive of. During these periods, forces, which we call Forces of Nature, but which are merely the instruments of the Divine Architect of the world, have been in incessant operation, and it is to some of the results of that unceasing action, in connection with once living things, that we have to look to night.

If it be true, as the doctrine of evolution requires us to believe, that animal and vegetable life began with some obscure germs, out of which, as ages rolled on, other and more complex objects were developed, and that in this way

plants and animals gradually increased in the complexity of their organisation as the world grew older, then, we should expect to find something corresponding with this order of development in the order in which plants and animals appear in the rocks. In the lecture of to-night, I hope to guide you in this direction, through what is called the Palæozoic age, the age in which many of the forms of life were very different from those now existing, but throughout much of which period certain types of organisation are found to prevail. Near the very bottom of the Laurentian series there has been found in Canada a very extraordinary object, a small magnified portion of a section of which is represented in Fig. 1. This is declared to be the oldest known fossil. There is some dispute as to whether it is a fossil, or a mere mineral

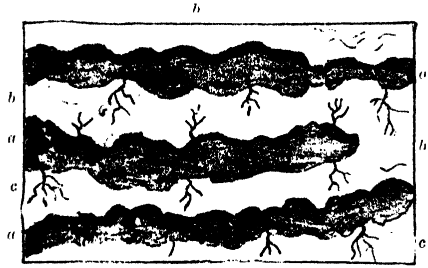


FIG. 1.—Portion of a section of Eozoon canadense. (*a*) Cavities occupied by the living animal. (*b*) Calcareous layers secreted by the animal. (*c*) Branching canals in the calcareous layers.

organisation. It is called the *Eozoon*, which means the "dawn of life." Now that this is a fossil I have no doubt whatever; if so, it is the earliest trace we have yet met with of any animal form. We know that there are certain little objects now living in the sea called Foraminifera; objects that possess microscopic shells made out of lime which they extract from the sea-water; and as the animals perish, their dead shells sink through the ocean and accumulate in its depths, where they form vast deposits of calcareous mud. The valley of the Atlantic is largely filled with these deposits. Each of these microscopic objects lives an independent life; they are very minute—the largest recent Foraminifer I have seen scarcely equalling the size of half-a-crown; and living forms of this magnitude are very rare; generally speaking they are like

the dust that we see blowing about the roads on a dry summer's day. And yet, put them under the microscope, and you discover that they are really organic atoms which often display exquisite beauty. Now the probability is that the Eozoon was a creature allied to these Foraminifera, but instead of existing as a multitude of minute and separate protoplasms, as is the case with our living forms, in the Eozoon these protoplasms blended to form thin extended layers of jelly superimposed upon each other. As myriads of minute polype animals combine, at the present day, to form coral-reefs many miles in length, so the united protoplasms of the Eozoon constructed vast reefs of foraminiferous shell. Assuming these opinions to be correct, what position does this primitive creature occupy in the scale of organisation? It is as near the bottom of that scale as it well can be. The only objects with which we are acquainted that are lower, are certain microscopic, infusorial creatures, little specks of jelly-like protoplasm, that are found in both fresh and salt water, and of which it is absolutely impossible that any trace could be preserved in a fossil state. Thus far then the earliest known fossil creature presents itself in a form consistent with the idea of evolution. The rocks reveal no further indication of organic life until we ascend to the series called Cambrian, found amongst the mountains of Wales, Westmoreland, and elsewhere. This group of rocks was chiefly investigated by that noble-minded man, the late Professor Adam Sedgwick of Cambridge, whose ceaseless energy, bright intelligence, and manly character, long will cause his name to retain a foremost place in the annals of English science. At a comparatively low horizon of this Cambrian series there have been found at one or two localities, but especially at a place called Bray-Head near Dublin, the remarkable objects to which the name of Oldhamia has been given. These objects are found in such quantities that layer after layer of the rock is composed of them. That they are organic, and not mere mineralised forms, the result of crystallisation, is indisputable. We are not absolutely certain what they were, but we have every reason for supposing that they were Corallines, allied to those found so abundantly on our sea-coasts.

This second fossil naturally suggests the question, What is the position of the Corallines in the scale of nature? We have ascended to a considerable height in the series of rocks, and we should expect, according to the theory of evolution, to

have made some advance in the organisation of any fossils which those rocks may contain. There is no doubt that the Corrallines come next to the Protozoa, to which group the Eozoon belonged; they occupy a higher position, but it is still low compared with what is to follow. Thus far objects continue to be arranged in their right order. When we ascend still higher in this series we come upon an extraordinary set of forms of wonderful diversity. The oldest shell that we have found is a minute creature, differing from the ordinary shells with which you are familiar. It belongs to a group well known to the conchologist and geologist as Brachiopoda, and of which the best known are called Terebratulæ and Lingulæ. These creatures occupy a position in the scale of organisation a little lower than such shell-fish as oysters, cockles, and mussels. It is to this somewhat lower group that the Obolella—the first form of shell-fish that has been found amongst the Welsh mountains—belongs. I do not mean to say that this is the oldest shell that ever lived: I merely say that it is the oldest of which we have found any trace. A little higher up we come upon a remarkable outburst of life; we arrive at a part of the Cambrian series in which we find a number of extraordinary creatures, called Trilobites. They are "crustaceous" creatures, allied to crabs and lobsters, but occupying a lower position in the crustacean series than crabs and lobsters do. Associated with these, we find fossil sponges, somewhat similar to those you are familiar with at the present day. These well-known objects began to make their appearance upon the earth even at this early period. Associated with these sponges and curious crustaceans, we also come upon objects known as Encrinites, representatives of which are still living in our seas. These are animals very closely allied to star-fishes, but which, instead of being free and able to wander hither and thither, are planted upon a fixed stalk. The stem does not afford nourishment to the star-fish at its top, but the star-fish affords nourishment to the stem; and although it has certain root-like organs, these do nothing for the creature beyond fastening it in the sand, in which it chiefly resides. They do not draw any nourishment from that sand as the roots of a tree would do; they merely fix the creature there. The mouth, which is in the middle of a terminal series of branching arms, receives the food that those arms entangle; and it is this part of the creature—the star-fish part—that nourishes the stem and roots, and not the stem and

roots that nourish the fish. These Encrinites now begin to be comparatively abundant; we shall find them still more as we ascend higher. Thus we see that we have already made a somewhat important advance in the development of animal life. Ascending still higher, we reach the Silurian group of rocks, for the investigation of which we are chiefly indebted to the labours of Sir Roderick Murchison. We were long

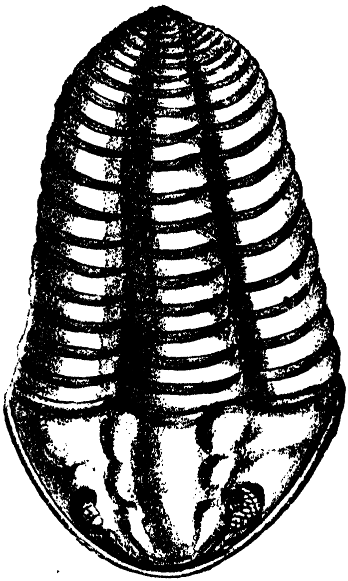


FIG. 2.—Upper surface of a Trilobite from the Silurian rocks.

familiar with the fact that, running down the border-land between England and Wales, there was a long line of fossiliferous limestones, of which little was known; they were only recognised by the vague name of Transition limestones. We merely knew that they were thought to be somewhat more modern than the older slate rocks, and somewhat older than the coal-beds of the neighbourhood of Manchester. But Murchison found that these rocks were as capable of being studied and arranged in chronological order as any other rocks with which we are acquainted, and the publication of

his great book, entitled *The Silurian System*, gave us the clue wanted to the understanding of the entire series. It turned out that this Silurian series of strata, which had been so long neglected, was not only richly fossiliferous, but was quite as much so as any rocks seen in other portions of the fossiliferous series. On entering this new region we still find that most of the types met with in the Cambrian beds lived into the Silurian age, though the species were different; we still have the Sponges and Encrinites. The Trilobites still occur, and sometimes in extraordinary profusion; in fact this Silurian age was the one in which they culminated; being more abundant then than at any period before or after. In the Arctic seas at the present day there are certain small creatures so abundant that when a whale opens its jaws and takes in a mouthful of water, after squirting the water out between the plates of whalebone, which serve as teeth, it retains a huge mouthful of these small objects. There must have been something like this in the ancient Silurian seas, because two of these Trilobites, the Trinucleus and the *Asaphus Buchii*, occur in such numbers, that entire strata largely consist of their remains. We now come upon certain things that we have not hitherto seen. We find, for instance, a group of extraordinary objects, called Graptolites. For a long time we doubted what these were, but they are now understood to be a remarkable group of Corallines. They were not found in the Cambrian beds, nor have we found them at a later period than the Silurian. I may refer here, whilst speaking of these Graptolites, to the great discovery which first erected geology into a science, and which was made by the veteran friend and tutor of my younger days—I mean the late father of English geology, William Smith. Previous to Smith's day the rocks were unclassified, because we had no means of estimating accurately their relative ages. Smith however discovered that in all this pile of strata—at all events in such portions of it as he was familiar with—each stratum or group of rocks possessed organic remains that were characteristic of that group, and that were not to be found in any other. Consequently, just as when you disinter some accumulation of buried antiquities, you see by the stamp upon the coins whether they belonged to Greek, Roman, or mediæval times, so the geologist, taught by Smith, learned to recognise, not, it is true, the actual age, but the relative age of the rock which he happened to be inspecting, by means of what my old friend

Dr. Mantell termed the "medals of creation." By this he meant the peculiar fossils which that rock enclosed within its stony matrix.

In strict accordance with Smith's theory, when we find these Graptolites we have every reason to believe we are dealing with Silurian rocks. In these rocks we also come across star-fishes. Thus you see we are steadily advancing into the midst of things with which we are still familiar in a living state. When we reach the middle and upper part of this class of rocks we find Corals extremely abundant; we find remains of Corals even among the Cambrian beds; but when we reach certain deposits in the middle and upper part of the Silurian system, we have the clearest evidence of the existence of tropical seas, because Corals like those that now flourish only within thirty degrees of the equator, have been as abundant as they now are in tropical regions. The limestone beds of Dudley, in the iron district, are almost entirely made up, in some places, of vast accumulations of tropical Corals. But besides these, we also find that there has been a rapid development in molluscan life during the Silurian age; and not only so, but we find here a remarkable development of that highest type of molluscan life known by the name of cuttle-fishes. I do not mean to say that we have actually found the cuttle-fishes themselves, but we have found shells which we know must have been embedded in the soft tissues of cuttle-fishes. When I tell you that some of these shells must have been seven or eight feet in length, you may judge what must have been the size of the living cuttle-fishes to which they belonged. Now mark what this means. Recollect how comparatively low our position still is in the scale of stratified rocks, and remember that these cuttle-fishes not only occupy the highest position in the scale of molluscan life—that is, the life of shell-fish—but that in many instances they approximate so near, in some parts of their organisation, to the vertebrate section of the animal kingdom, as almost to constitute a connecting link between the one and the other. For instance, the cuttle fish has a brain enclosed in a cartilaginous cranium, a brain-pan made of gristle. Now here we clearly have an approach to the skull of the vertebrate type of animals. Still further; the cuttle fish has special ganglia, or masses of brain, set apart for the exclusive purpose of giving origin to the nerves of sight. This is precisely what occurs in our own bodies. The nerves of sight in the human body

arise from two special nervous ganglia, the "optic ganglia"; and we find two perfectly distinct ganglia, one on each side of the brain of the cuttle-fish, from which its nerves of vision proceed. Thus we see that, in more respects than one, these cuttle fishes and their innumerable allies, not only occupy a high position in the scale of molluscan life, but they almost form a stepping-stone across the boundary which connects the molluscs with the vertebrate animals. In the Silurian age not only were these cuttle-fishes represented by the Orthoceras, but we find other external chambered shells of the same general type corresponding to the living Nautilus.

But we must advance yet a step higher. There have been found in the uppermost parts of this Silurian series of deposits the remains of fishes which are met with here for the first time. One of these fishes, the Cephalaspis, so much resembles a large Trilobite in form that, when first found, we need not be surprised at its having been mistaken for one. Further investigation, however, showed very clearly that it was a true fish. It might readily have been supposed that the Cephalaspis was a crustacean in course of development into a fish; but the peculiar shape which suggests this idea is only one of those outward resemblances, devoid of real identities, that are apt to mislead imaginative minds. When we examine the organisation of this object, we find that it had genuine bones like other fishes, and that its hard structures were altogether distinct from the peculiar integument that constituted the protecting covering of the crustaceans.

But associated with this Cephalaspis there also existed in the later Silurian days another fish. And now comes one of the perplexing facts which geological investigation has brought to light, and which appear unfavourable to the doctrines of development and evolution. Murchison first showed that in the upper Silurian beds there existed the remains of species of shark, and other observers have verified the statement. When we inquire what position the sharks occupy in the scale of fish-organisation, we learn that they occupy its summit. They possess at the present day a brain organisation which brings them extremely near to the reptiles. There is every reason to suppose that the particular fossil found in these Silurian beds is not only a shark, but that he belonged to one of the highest types of the sharks. We have here a seriously awkward fact. Nature has apparently taken a step forwards, in advance of her time. Between these sharks and the lowest forms of fishes

there exists a vast series of fishes such as we see in our markets, but which have apparently no representatives in this ancient epoch. In the first place, if you take a salmon or a cod-fish you will see that its vertical tail divides into two nearly equal lobes; and if you trace its long vertebral column or backbone, you will see that it terminates midway between the upper and the lower lobes of the tail; but no such fish is to be found in any of these more ancient rocks. Before we can find fish like the recent ones, so far as the tail is concerned, we must reach the Oolitic period. Up to this point of time all the fishes that we find are either sharks, or belong to another great group, the Ganoids, of which I shall have to say a word or two presently. Here, then, I repeat, we have a difficulty. We cannot bridge over the gap which connects these sharks with the lower forms of animal life which I have been endeavouring to describe. What future research may do to remove this stumbling-block we cannot tell—but at present it does stand as a serious hindrance to our unreserved acceptance of the evolutionary theory.

But we must now pass another of the boundary lines dividing separate groups of strata, when we shall reach the Devonian beds; these are a very remarkable series of rocks, the relations of which have only become intelligible to us of late years; but they will have a special interest for some of you, if, as is probable, I have some Scotchmen amongst my audience. It was from amongst this series of Devonian beds that one of the brightest intellects of Scotland fought his way up from wielding a stonemason's hammer to becoming editor of one of the ablest of the Scotch newspapers, and the author of some of the most eloquent descriptive books ever written by mortal pen—I mean the late Hugh Miller. Now Miller, and others who followed in his footsteps, brought to light from this Devonian series of rocks a very remarkable set of fossils. I won't dwell upon the shells and other curious objects found in these rocks, for time is short, but I will call your attention to some of the fishes with which he first made us acquainted. One of these is the Pterichthys, an extraordinary looking fellow, with two wing-like appendages hanging by his side, and covered with an armour of large angular plates that remind us more of a tortoise than a fish. The Coccosteus is another, and if possible still more curious fish, with a tadpole-like head, resembling in shape those black and slimy froglets and newtlets that dabble at the margins of our ponds in early spring. But besides these examples we have other modifications

of the Ganoid fishes, in which rhomboidal scales overlap each other like the slates of a house, and in which the vertebræ of the tail run very conspicuously into the upper lobe.

The group to which all these fishes belong is not yet quite extinct. It continues to be represented by the bony pike of North America, and a similar fish, called the Polypterus,

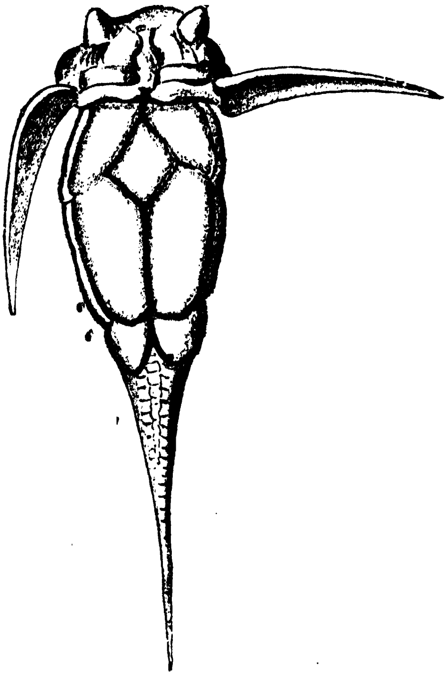


FIG. 3.—Under surface of a Pterichthys from the Devonian rocks.

is found in the Nile and in other rivers of Africa. In addition to the scales of these fishes differing from those of the cod and salmon in outward form, they are also much more bony in their internal structure. Ascending through the whole of this pile of ancient rocks, we discover no kind of fish excepting members of the shark tribe, including their relatives the skates, and these Ganoid fishes, until we reach the Chalk strata.

We still find in this Devonian bed the Cephalaspis, which continued to linger through the earlier parts of the Devonian age. But, before we leave this age I must introduce to you another acquaintance whom I have previously neglected but whose race began its career during the epoch of the upper Silurians which we have already considered. He is called the Eurypterus, and is a sort of half-developed lobster. He grew to the stature of an adult, whilst he retained some of the organisation of his earlier life. He seems as if his limbs had forgotten to grow along with his body. But when I tell you that he was often six or seven feet long, you will see that he would afford an excellent dinner to one of the lobster-loving sharks of that ancient date. He disappeared entirely at the close of the Devonian age, and there has been nothing like him since. I suppose the sharks of that period ate him up, and there was an end of him. "We shall not look upon his like again."

Thus far I have made no allusion to the vegetation existing on the earth. We find vague traces of plant-life in the Silurian and Cambrian beds, but, so far as we can ascertain, those plant-remains are merely fragments of seaweeds; we have no very definite evidence of anything higher than seaweeds existing in those older days. For a long time we were equally unaware that any higher flora lived in the Devonian age; but my friend Dr. Dawson, of Canada, has, within the last few years, revealed to us the existence of magnificent forests during this geological period. This flora corresponds very minutely in all its general features with that seen in the coal-beds surrounding Manchester. For instance, we find in it extraordinary Calamites, huge plants allied to the horsetails of the present day. Then it contained Lepidodendra, gigantic representative of the dwarfed, living club-mosses, but instead of creeping along the ground, and barely lifting their heads twelve inches from the soil, these were magnificent trees, rising 100 feet into the air. Then we also had a rich array of ferns. We must not overlook the notable fact that in these Devonian beds this wonderful flora bursts upon us with almost the suddenness of a flash of lightning. Most of its plants are what botanists call cryptogamic; that is, plants that have no flowers, but merely develop what are termed spores, and not true seeds. But side by side with them we find a wonderful display of coniferous plants, allied to the tribe of pines and firs, and which we know to be flowering and seed-bearing plants; but

they are flowering plants of a very peculiar type. Whether we may consider them as having a higher or lower organisation than oaks or elms, is a point on which opinions differ; but our best botanists incline to regard them as connecting the cryptogamic Lycopods on the one hand, with the flowering trees on the other. There exists no evidence showing that any of our ordinary forest trees grew on the earth in this Palæozoic age. Up to the close of this vast period the flora was confined apparently to these cryptogamic plants and conifers. We must

FIG. 4.—Pinnule of a Fern from the coal-measures.

not overlook the notable fact that this wonderful flora bursts suddenly upon us. We have yet found no indications of a previous and less highly-organised flora, out of which that under consideration might have been directly developed, at the same time it is possible that some such may have existed without any traces of it having been preserved in the older rocks.

We must now leave the Devonian age, and come to the

Carboniferous beds, that is, to the group of strata to which our British coal-measures belong. These, of course, are beds that interest us in every sense of the word, and were I to deal fully with them it would take an hour, even to clear the ground. I need scarcely say that the Carboniferous age has left rich blessings to mankind. Though it is not the only geological period which has supplied the world with that invaluable article of fuel which we call "coal," it is undoubtedly *the* period in which the finest and most widely diffused beds of coal were accumulated, and consequently our manufacturing interests owe more to this than to any other series of deposits. Not only is it our chief source of coal, but it is also that from which we draw our most valuable supplies of iron. So that here we get, side by side, the raw materials for the construction of our machinery, and the fuel by which that machinery is to be worked. At the time when the coal-measures began to accumulate our country exhibited very different outlines of land and sea from what it does now. If we go to the lowest of these Carboniferous strata in Western Yorkshire and Derbyshire, we there find the rocks in the shape of grey limestones—the Derbyshire limestone, with which most of you are familiar, and of which you make use in building your garden-rockeries; on visiting Derbyshire you see these limestones, rising on all sides, constituting the vertical cliffs that add such a charm to Derbyshire scenery. The fossils which they contain show that these limestones have been accumulated in a deep sea, which covered Derbyshire and the adjoining parts of Yorkshire. But when we cross over into Fifeshire and the neighbourhood of Edinburgh, we find that these thick strata of marine limestones are altogether absent. Whilst Derbyshire was deep under the ocean, there flourished in North Britain magnificent forests, analogous to those I have been describing as existing in the Devonian age By and by, however, in our midland part of the country, the sea gradually became filled up with its accumulating organic sediments, in addition to which it is probable that the land itself slowly rose, and after passing through a transition period, in which sea seemed to struggle with land for the mastery, we arrive at what we call the Mountain coal mines. These are a series of very thin coals, which run along the hill-sides of Halifax and Oldham, and one of which, cuts horizontally through the top of Rivington Pike. Every bed of this coal represents the beginnings of an ancient forest. As

yet the forests of this district evidently had not attained to any prolonged duration, as is indicated by the thinness of the coal-seams; but when we rise a little higher we come to the rich coal-mines round Wigan, such as the Arley mine and others, with beds of coal from five to seven feet thick, and which have been entirely produced by the decay of the leaves, branches, and prostrated trunks of the forest-trees which accumulated on the ground where the coal-beds now exist.

We have now reached dry land and forest life. There is evidence amongst these beds that not only did plants grow, but that land-shells flourished under their shade; two land-shells having been found in coal-beds of this age in Canada. One is a true snail-shell, and the other is a Pupa—a genus of

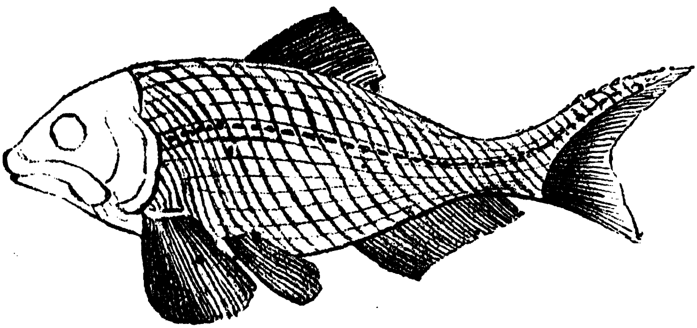


FIG. 5.—A Ganoid fish from the coal-measures with the "heterocercal" tail, *i.e.*, having the vertebral column prolonged into its upper lobe.

molluscs allied to the snails still found living in our own woods. If you were to examine the trees growing in the damper parts of Bowdon Woods I have no doubt whatever that you would find shells of the same kind adhering to their bark. We have also clear evidence that insects abounded at this period. Spiders, too, were not wanting, spiders of large size having been found in some of the ironstones of this Carboniferous age. Numerous shark-like fishes were associated with equally numerous Ganoid ones in the deeper waters, all these fishes having the "heterocercal" tail of Fig. 5, which represents a Ganoid from the coal-measures. In the marshes and estuaries there existed numerous Batrachians, or reptiles allied to the frog and newt; but some of which must

have been almost as large as crocodiles. Combining all these facts, we find that so far as animal life is concerned we are steadily rising in the scale of organisation, and approaching nearer to living types; but so far as vegetable life is concerned, we are still in the same position as we occupied in the Devonian age. We find now that amongst the trees there still are gigantic horsetails, relatives of those which you see in our ditches and ponds at the present time; the latter plants are generally not more than a foot or eighteen inches high, though occasionally reaching to four or five feet: of which size I have found them in the damp parts of Derbyshire. But what size were these fossil "Calamites"? I have specimens of these ancient horsetails in my cabinet that must have been twenty or thirty feet high, and with stems nearly as thick as my waist. Then we have the plants already referred to as allied to our club-mosses. I mean the Lepidodendra and Sigillariæ, and we find that they often rose to 100 feet in height. We have in the Owens College museum a carefully-made cast of one of these huge stems, discovered at Dixon Fold, on the Manchester and Bolton Railway, and which measures twelve feet in circumference near its base. How very peculiar must have been the aspect of forests composed of such gigantic cryptogams!

There was also an undergrowth of ferns and smaller horsetails, with here and there a few Tree-ferns vainly aspiring to rival the aristocratic Lycopods that towered above their heads, and on the drier uplands the pine-forests appear to have flourished apart from their cryptogamic neighbours. There is evidence that the climate of that Carboniferous age was not that of our temperate region. We have reason to suppose that it was a warm one, but we have no proof that it was tropical in its character. Whatever it was, it was the same in Greenland, in Central Europe, and in Australia, since in all these remote localities we discover similar fossil plants in the Carboniferous beds. There must have been a peculiarity in the physiognomy of these Carboniferous forests. No flowering plants gave local colour to the landscape. There were no grassy meadows covered with daisies and buttercups, or rich moorlands glowing with the purple and gold of heather and furze. The entire aspect of the vegetable world must at that time have been something like what Mr. Wallace tells us is so characteristic of tropical forests in the present day, where we see every shade of green. The earth is ladened with the

luxuriant vegetation which it supports, but you have no masses of flowers giving distinctive colouring to the landscape. You have, it is true, individual trees that are rich in their gorgeous bloom, but they are isolated and lost in the verdant expanse. Such also must have been the hue of the woodlands which flourished in the Carboniferous age.

As we ascend through the Carboniferous rocks we find that marine objects become gradually fewer in number. In the older beds a great many of the types of shells that characterise the Silurian and Devonian ages still flourish. We find Corals and Encrinites; we also discover a few small Trilobites which still linger, but which now take their departure and we see them no more; but as they disappear we have evidence that their place is being taken by the living Crustaceans that may be regarded as the nearest relatives of these Trilobites – I mean the curious Limuli, or king-crabs, now found in the tropical parts of the world. The king-crab, which exists in the seas of many tropical regions, is very like the Trilobite in its structure and general appearance; and the advocates of evolution would contend that the king-crab was evolved from the Trilobite. Be this as it may, I can only say that we have the last descendants of the expiring Trilobites preserved in the Carboniferous rocks, and, side by side with them, we have the Limuli beginning their race of life. The former are the latest of all known Trilobites, whilst the latter are the earliest of all known king-crabs; but there is not the slightest indication of any transmutation of the one into the other of these two fossils. Of course it is not impossible that there may have been embryonic links establishing a transition from the Trilobite to the Limulus, but geology gives no evidence whatever of the existence of such links. The Limuli are very definite in their shapes, and cannot by any stretch of the imagination be made to merge into the little worn-out Trilobite that was evidently coming to the end of its days.

Above these Carboniferous rocks we have a group called the Permian beds, upon which I will not dwell long. If you go to the neighbourhood of Collyhurst, near Manchester, you will probably still find traces of an old quarry, called the Vauxhall quarry. That quarry was well known thirty years ago, because it was from it that the Manchester iron-founders of that period obtained sand for constructing moulds in which to make their iron castings. Now that sandstone rests upon

the coal strata, and forms the base of this Permian series of rocks. Then there were found, not far from Vauxhall, a few thin layers of limestone; and in the neighbourhood of Bedford, near Worsley, these limestones are a little more fully developed. These limestone rocks contained peculiar fossil shells characteristic of the Magnesian limestone, which is a member of the Permian series.

On going eastward across the Lancashire hills we come to a series of beds of yellow limestone, which you will see in cuttings in the neighbourhood of Wakefield and Normanton: these again are the same Magnesian limestones as those thinner ones found in Lancashire. When we reach Durham we find this same limestone still further developed, attaining in that district a thickness of something like 500 feet. It is obvious that the sea in which these limestones were deposited was a shallow one in western Lancashire, and deepened as we approach the Durham coast. This Magnesian limestone—so called because it contains a small percentage of Magnesia mixed with calcareous matter—is rich in fossil remains. Many of these remains are peculiar. They are fossils that we have not found in the Carboniferous beds below, or in the Triassic beds above; some of these Permian beds are often exceedingly rich in the remains of Ganoid fishes; but though the species are distinct, the types are similar to some found in the Carboniferous strata. . . . The chief importance of these beds to us now is found in the circumstance, that in the neighbourhood of Bristol the remains of reptiles of a higher order than any we have hitherto met with have been found in them. These reptiles are partly allied to the lizards and partly to the crocodiles.

Thus we see that so far as we have accomplished our ascent from the lowest to the highest strata, race has been supplanted by race, generation has followed generation; occasionally we have seen evidence that seemed to indicate the existence of links connecting a departing race with another that succeeded it; suggesting the possibility of a gradual transition having taken place from lower to higher forms as years rolled by. There are also broad general indications of an upward progress, shown by the introduction, from age to age, of animals having a higher organisation than those which preceded them. But nothwithstanding this we are obliged to admit, that when viewed in minute detail, the rocks which we have examined give but a very limited support to the doctrine of evolution.

I will not dwell upon this subject now, because I shall have to give you a slight *résumé* of the matter in the concluding lecture of the series. I have thus far guided you only through the Palæozoic series of rocks; and that but hastily and imperfectly, because of the limited time at our disposal. I have only been able to give you a bird's eye view of the country over which we have been travelling; trusting that you will again go over the ground by yourselves, and in a more detailed and leisurely manner.

THE SUCCESSION OF LIFE ON THE EARTH.

LECTURE II.

In my last lecture I conducted you through what is called the Palæozoic period of geology. You will recollect I pointed out to you, in that lecture, that geologists roughly divided the time, during which the earth has been undergoing geological transformations, into three great ages: the Palæozoic, or ancient age; the Mesozoic, or middle age; and the Cainozoic, or recent age.

The Palæozoic age, which we dealt with last Tuesday, is characterised equally, as we saw, by the creatures which lived in it and by the creatures which did not then exist. We found that there were special types of living things which flourished, more or less, throughout even the later portions of that age. But we now cross a boundary line, beyond which we find evidence of a great change. I do not mean to say that all the genera we shall meet with are wholly new, because such is not the case. On the contrary, there are large numbers of types and patterns that appeared upon the earth in the earliest portions of its history, which never passed away again, and which are living at the present time; but, whilst this is perfectly true, it is equally so that, at the boundary line we are now crossing, like passing from one hemisphere to another, we leave behind many things that we have become familiar with, and are brought face to face with new forms of organic life. The boundary line of which I now speak comes high up in the scale of rocks. Judging from the immense pile of strata through which we have already ascended, you might suppose that we were arriving near the end of our journey. But this is very far from being the case. You will learn, as we proceed, that, though the thickness of the remaining strata is insignificant, the interest of their organic contents, and the vast changes which those organisms have undergone, becomes increasingly remarkable. There seems to

have been a marvellous quickening in the power of developing life as the world grew older. During the earlier stages of the vast Palæozoic age, the progressive development that took place advanced much more slowly than it did towards its close—and we shall find that after entering upon the Mesozoic period, the rapidity with which that development increased becomes more and more marked as time advances.

Leaving the Palæozoic rocks, we come to the base of the Mesozoic series, represented by what are called the Triassic formations. These are strata with some of which you have the opportunity of becoming sufficiently familiar, because the most conspicuous of them is that red sandstone which you see extending in so many directions around Manchester, but especially throughout the whole plain of Cheshire. The red sandstone, and the marls that surmount it, are especially rich in the rock-salt which is extracted from the salt-mines of Northwich and various other parts of Cheshire. But it is not with the physical and inorganic features of this age that we have now to do.

At the same time I must just mention that there exists in the middle of this series of Triassic rocks in Germany a comparatively thin limestone-bed that is rich in fossil shells. The occurrence of this "Muschelkalk" is rather important to us, since we happen to have in Britain no representative of this stratum, and, but for its existence elsewhere, we should have been very ignorant of much of the life of the Triassic age. The Triassic rocks seen in England are extremely barren of fossils. At the same time they do afford us some information which we shall find to be significant. In the first place, the Muschelkalk tells us that the family of Encrinites is still represented; all the types of this group which are found so abundant in the Palæozoic beds have disappeared; every one of those numerous species have become extinct. In their place, in this German Muschelkalk, which, translated into plain English, merely means "shelly limestone," we find a new Encrinite, a true member of the Crinoidal family and yet altogether different from those whose place it has taken. The question inevitably arises, "How and whence has this new Encrinite come?" It is very distinct from those of the Carboniferous rocks; merely preserving the general plan and pattern according to which they are all constructed; we cannot so connect it with any of the extinct forms as to suggest a probability that it has descended directly from them; it

is the isolated known representative of the vast race whose place it has taken so far as the Triassic strata are concerned.

Then there are shells peculiar to this age, but I need not dwell upon them. Most of them are merely useful to the geologist in helping him to identify the particular rock that he may happen to be examining. But the case is different when we turn our attention to some extraordinary creatures which, in all probability, once roamed over the very spot where you are now sitting. The history of these creatures is decidedly peculiar. In the first instance there were found, at Corncockle Muir, in Scotland, some slabs of sandstone, the surfaces of which exhibited impressions of what were evidently the footsteps of four-footed creatures. These impressions were generally found on marls that were covered over with a bed of sandstone. The impressions in the clay were hollow, and of course the sandstones that filled up these hollow impressions were in relief. It very soon became clear that, whatever the creatures were to which these marls owed their existence, they had been living things that had walked upon a half-sandy, half-muddy tidal shore, and had left their footsteps as they travelled along, which footsteps had become hardened by the sun before the returning tide was able to wash them away. These impressions afterwards became covered with layers of sand, which protected their sharp outlines from injury, until they were once more brought into daylight by the labours of the quarryman. We have strong reasons for concluding that these footsteps were formed on a tidal shore, and the evidence that leads us so to conclude is of a kind that is perfectly available to every Manchester man. As you walk through the streets of Manchester you may have noticed the difference between the flags of our pavements and those you find in the towns of western Yorkshire; for whilst those of Yorkshire are almost as smooth as the platform upon which I stand, those of Lancashire are rough, often marked with irregular, wavy ridges and furrows, not altogether comfortable to walk upon. Now what do these ridges and furrows mean? You can easily answer this question for yourselves if you recall the similar irregularities constantly left by the retiring tide on the sands of Southport and Blackpool. When tidal waves are moving slowly over a layer of mud or sand, some remarkable movement of the water, that is not clearly intelligible, produces these ridges and furrows. The sandstone from which we have obtained these fossil footsteps often exhibits ridges and furrows

exactly similar to those recent ones to which I have called your attention; and as we never see them excepting where there has been flowing water, and especially tidal water, we come to the conclusion that the sands on which these footsteps were impressed were covered periodically by the tidal wave.

The next question is, by what sort of being were these footsteps made? We must go to different parts of the world for a full response to this query. These footsteps have been found very abundantly in our own Cheshire district; magnificent examples of them occur near the village of Lymm, and another remarkably fine set of them was discovered at the Stourton quarries, near Liverpool. Examining these footsteps more minutely, we see, in the first place, that there are two sets of them; there is one series of very large impressions produced by a large foot; and alternating with these is a corresponding series of much smaller ones. Since these impressions very much resemble those which would be made by pressing the outspread palm of the hand upon soft, wet sand, before any remains of the creature which made them had been found the latter was called the Cheirotherium, or beast with a hand. From the regular alternation of large impressions with small ones it was clear that the fore and hind feet of the creature had varied greatly in their dimensions; and further examination led to the conclusion that the smaller feet had belonged to the fore limbs and the larger feet to the hind ones. The probability that this was the case led naturalists to conclude that the animal had been a huge Batrachian, a near relative of the frogs and newts. In time a few of its bones and teeth were discovered; and so far as they went, they gave support to the above conclusions. After this, still more perfect examples were obtained, which leave no doubt that geologists were correct in the opinions they had formed respecting the nature of the Cheirotherium. But before this identity of the foot-prints and the fossil bones was established, the name of Labyrinthodon had been given to the latter by Professor Owen, owing to a remarkable labyrinthine pattern exhibited by transverse sections of the teeth, peculiarities which he described and figured in one of his works. This creature was one of the most remarkable animals living in the age of which I am speaking. Not that it appears here for the first time; later researches have shown that similar animals lived amongst the marshy forests of the Carboniferous

age. Not only have magnificent skulls of this creature been found in the coal-beds near Glasgow and other places, but impressions of his footsteps have been found, similar to those belonging to the Triassic period. Owen's name of Labyrinthodon is now generally identified with this strange creature, in which science, art, and commerce, meet very strangely together. When Owen obtained the first of its teeth, he found in transverse sections of it the labyrinthine structure, to his figure of which I have already called your attention; very shortly after that drawing was published it reappeared in Manchester, forming the centre of a printed pocket handkerchief!

Even in England the footsteps of several other reptiles appear along with those of the Labyrinthodon. Some of these footsteps look much like those of tortoises, but whether this is really the case or no, we are not sure. In some limestone beds near Bristol there have been found the bones of some reptiles of unquestionably higher organisation than Batrachians, whilst at Elgin, in Scotland, besides a small lizard like animal, the remains of a huge crocodilian creature have been disinterred from beds which are now generally admitted to be of the Triassic age.

However remarkable the footsteps of our British reptiles may be, they are insignificant compared with what occur abundantly in the United States. Such footsteps have been found there in immense numbers, and of at least twelve species of lizards, tortoises, or turtles, and Batrachians. But here another type of footstep abounds—viz. those of at least thirty-two species of three toed bipeds, believed to be those of birds like the ostrich—but some of which must have been four times as large as the living ostrich, and yet of the actual remains of all these numerous creatures no fragment has yet been discovered in the sandstones of Connecticut.

Turning to the Triassic plants, we discover that the old Coniferous species of the coal-measures are gone, and are replaced by other forms, such as the genus *Voltzia*, which is altogether new. We do, however, find in these Triassic beds some representatives of the Calamites, or ancient horsetails, which are so common in the coal measures, but they are feeble representatives of their ancestors. As these ancient horsetails disappear, their place is taken by the true modern horsetails, which we find for the first time in the newer Triassic rocks of the neighbourhood of Strasburg and elsewhere. We call this

fossil genus Equisetites, to distinguish it from the living Equisetums; but I have no doubt, both from the organisation of its stem and the peculiarities of its organs of fructification, that it is a true horsetail, differing chiefly from the living ones in the large size to which it attains; instead of the diminutive plant we now find in our marshes, it grew to a height of twenty or thirty feet. Interested in the origin of this Equisetites, I made a journey to Strasburg to examine the specimens in Professor Schimper's well-known Strasburg museum. I wanted to see if I could detect anything in the Triassic Calamites, found in that district, that would show a transition from the Calamitian type of the coal-measures to this Equisetaceous type; but I could not find the least indication of transition from the one to the other. The characteristics of each of these two appeared to me perfectly definite, and not in the least to merge into each other. Whether any transitional form ever will be discovered, uniting the ancient to the modern forms, remains to be seen; but at present geology reveals no such transition. The old race, which we found to be most abundant and widely prevalent through the age of coal, as well as through the Devonian period, now dies out under the influence of agencies unfavourable to its continued life, and a new one takes its place, coming we know not how or whence.

We further find in these Triassic beds traces of a group of semi-tropical plants called Cycadeæ, which do not occur in these temperate regions, but which abound just outside the tropical zones of both the Old and New Worlds, where the tree-ferns, india rubber plants, and pepper-trees flourish. Recent investigations have made it more than probable that some of these plants flourished in the Carboniferous age.

But I must now cross another of the boundary lines which separate one age from another. We pass from the Triassic to the Oolitic strata. At this point of transition we meet with some new phenomena. In the first place, there have been found in two or three parts of Europe—including our own country—some fossil teeth of a true mammalian quadruped, and found so near our last boundary line, that opinions have differed as to whether the fossils belong to the Oolitic rocks above or to the Triassic rocks below. We have hitherto seen no representative of this division of the animal kingdom. Hence, so far as we now know, this "Microlestes," as the creature to which these teeth belonged is called, is the oldest of known mammalia.

It is somewhat dangerous to attempt to reason from a few solitary teeth as to the nature of the animal to which they may have belonged; but the probability is that it was either a Marsupial creature, that is a creature somewhat allied to the Opposums of America and Australia, or if not that, to some animal of a closely-allied type. I shall have to refer again to the question of Oolitic mammals as we proceed; I merely mention it now because of the position in which these remains were found. For some time after the discovery of this animal it was generally regarded as an Oolitic fossil, but later investigations indicate that it really belongs to the upper part of the Trias; be that as it may, it constitutes the first known example of that profuse mammalian life that is now so abundant on the earth.

Before actually crossing our new boundary, I must call your attention to a most extraordinary and anomalous state of things existing at two localities in South-eastern Europe. I have told you that throughout the world many of the Palæozoic types of life disappeared even before the close of the Triassic age; but at Hallstadt and St. Cassian, the Palæozoic and Mesozoic ages seem to have overlapped in a most exceptional manner. We have found nothing like it in rocks of this age in any other part of the globe. At these spots we find many of the Silurian and Carboniferous types, which we thought had disappeared altogether, intermingled with some of the most characteristic fossils of the Oolitic strata—a combination which is altogether of an exceptional character.

These Oolitic rocks are so designated because they contain a large number of limestones made up of little rounded granules, which resemble the eggs, or what you commonly call the roe, of fish. So close is this resemblance, that you might imagine lumps of limestones to be the petrified ova of some fish. We now know this is not the case; these little rounded atoms are merely the results of mineral changes which the rocks have undergone after their original accumulation; we can observe similar "Pisolites," as they are called, forming in "Travertins," or modern calcareous accumulations precipitated from hot springs in several parts of Italy.

The Oolitic age has been very appropriately designated the "age of reptiles." It certainly was a period in which reptiles were the dominant creatures; and such is often their peculiarity of form that we may say to each,

"Thou comest in such a questionable shape."

When you examine the extraordinary things represented in my diagrams, I think you will admit that this Shakespearian passage is strictly applicable to them. Were I to describe all the forms of animals that occur in this Oolitic age, I should detain you longer than our time will admit of my doing; so I must select certain salient ones upon which to dwell. We still discover remains of the lower form of animal life, such as the sponges, star-fishes, and Encrinites. The various types of marine shells now multiply in a very rapidly-increasing manner, compared with what we found to be the case in the rocks lower down in the geological scale. Not only so, but every individual species that we discover is new, and, in many cases, the large groups of species which we call *genera* are equally new. I will give one illustration of what I mean. I spoke to you of the Brachiopoda, those extraordinary shells which are so abundant in the Cambrian, Silurian, and Carboniferous ages. There are certain of these Brachiopoda represented by two well-known genera, which are the centres around which many other similar genera are grouped; I mean the genus Productus and the genus Spirifer. Now these two names represent two vast groups of species of shells, which occur in enormous numbers in the Palæozoic beds; but they have all gone out of existence, with the exception of one or two solitary forms that have just survived long enough to reach the base of this Oolitic age where they finally disappear. Ascending to the higher mollusca, we come to a very remarkable change in the opposite direction. I spoke to you the other day of the existence of Cuttle-fishes in the ancient age, and pointed out that even in the Cambrian and Silurian beds we had shells that unquestionably belonged to that group of molluscs. There is living in the sea at the present day, especially in the seas of the Malay Archipelago, a well-known shell, designated the Nautilus. This Nautilus has a spiral shell, with numerous transverse partitions dividing its interior into a series of chambers, whilst the animal constructing the shell resides in a large terminal chamber. This means that originally there was but one chamber, in which the very young mollusc lived, but as the animal grew it enlarged its shell to make room for its growing body. If you look at the outline of the soft animal you will see that he has a rounded base, and that for it to have dwelt in the open mouth of a tapering cavity, where there was nothing to prevent his being incon

veniently pressed backwards into the narrowing portion of a spiral cone, must have been far from comfortable. We should be in a similar position if required to sit in a large chair, the seat of which was made like an inverted extinguisher. But

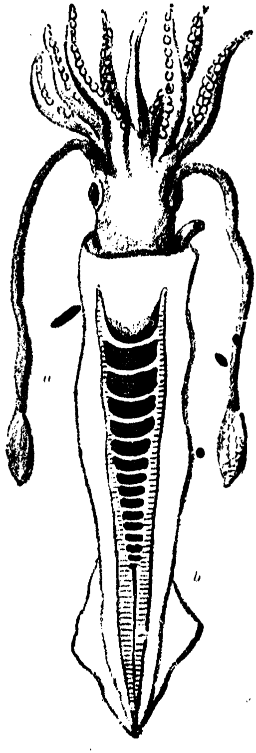


FIG. 6—Diagram of a Cuttle-fish containing a Belemnite. (a) Chambered shell of Phragmacone of the belemnite. (b) Solid extremity of the Belemnite.

the Nautilus escapes from this uncomfortable position by shutting off behind it such portions of the shell as are too narrow for its body; it effects this by constructing a transverse partition of shell, the concavity of which fits accurately to the outline of the posterior part of its body. In whelks and periwinkles no

arrangement is needed, since, in them, the animal always corresponds in length and form to the entire cavity of its shell. The animal which makes itself comfortable in the way described is merely a modified Cuttle-fish. There are two great groups of these creatures, both of which are represented in a fossil state —viz. those whose shells enclosed their bodies, as in the Nautilus —and those whose bodies enclosed the shell, as in most of the Cuttle-fishes. Both these types abound in the Oolitic rocks. In a few cases the entire Cuttle-fish, with its contained chambered shell, is perfectly preserved. You will remember we believe this to have been the position of the gigantic Orthoceræ, met with in the rocks belonging to the Carboniferous and Silurian ages. That gigantic Cuttle-fishes formerly existed is probable enough, since a huge one has been discovered on three or four occasions living in the Atlantic, of which the body and arms together are more than thirty feet in length.

The study of these Cephalopods, as the entire group of Nautili and Cuttle-fishes is called, affords an interesting illustration of the progress of life on the globe. In the Cambrian and Silurian ages we had true Nautili and Cuttle-fishes, and in the Carboniferous age we again find similar objects; but associated with the former we now find a new nautiloid shell, called Goniatites, to be very abundant. There is a bed of ironstone, called Ganister running through our Yorkshire and Lancashire uplands, which is full of these Goniatites; this genus is essentially characteristic of the Carboniferous age. When we come to the Triassic age we find that the Goniatites are gone, and are now represented by another genus, the Ceratites. On crossing the boundary separating the Trias from the Oolites, we find that the Ceratite has disappeared in its turn, but we find in vast numbers, associated with true Nautili, creatures known by the name of Ammonites. These Ammonites are spiral shells, like the Nautilus, with this difference, that while the divisions between the chambers in the Nautilus are simply concavo-convex, in the Ammonites their surfaces undulate in an extraordinary manner; so that their margins, as seen on the surface of the fossils, look more like the foliage of a tree than anything connected with molluscan life. These Ammonites accompany us all through the Oolitic period; from the Liassic rocks up to the top of the Chalk which surmounts the Oolitic pile of strata, they are extremely common, but they are confined to the rocks of the Oolitic and Cretaceous ages. Associated with these Ammonites throughout the same periods

we find true Cuttle-fishes, and also curious fossils, which have long been known to the provincial mind as "thunderbolts." In shape they remind us somewhat of Sir Jos. Whitworth's pointed shot and shell. Formerly it was the popular belief that every flash of lightning was accompanied by the fall of a "thunderbolt;" and the ignorant multitude identified these oblong fossils with the supposed electric product. They are, however, merely chambered shells, somewhat like the Palæozoic Orthoceras, but in which the chambered portion occupies only the upper and inner part, whilst the lower part is weighted by a solid, investing, semi-crystalline mass.

In the Cretaceous period other Nautiloid forms known as Hamites, Ceratites, &c., abound—forms only found in the Cretaceous strata—but on entering the Tertiary age all these Oolitic and Cretaceous types pass away leaving only forms of Nautili and Cuttle-fishes, similar to those which still flourish in our existing seas.

Leaving these mollusca and advancing to a higher stage, we come to fishes and reptiles, and here it is that the marvels of the Oolitic age begin to present themselves. The fishes are still confined to the two groups, the *Ganoids* of Agassiz and that containing the sharks and rays, but in many of the Ganoids we now find, for the first time, the posterior extremity of the vertebral column terminating on the centre of the tail. (See Fig. 9.)

It would be vain to attempt to dwell upon a tenth part of the reptilian forms that characterise this age; I can only select a few of them. The seas in which these reptiles lived were probably tropical, since, in many parts of the range of hills extending from the coast near Scarborough to the banks of the Severn, we find the limestones abounding in corals of the tropical type and not unfrequently existing in the form of true coral-reefs. One of the strangest of the reptiles is the Ichthyosaurus; a formidable creature of great size and power, aquatic in its habits. When I tell you that he was often from 20 to 30 feet long, that I have seen the teeth three inches in length, and that his immense head is furnished with long rows of them, you will admit that he is not exactly the kind of creature one would like to encounter when bathing. Associated with this gigantic fellow, was the gentler and more graceful animal called the Plesiosaurus. He lived in the same seas, and was, like the Ichthyosaurus, an aquatic animal; both of them were carnivorous; of that there is no doubt, because in some of the

specimens, we have actually found in the place where the stomach ought to have been, the remains of their last meal, and can thus identify the fishes upon which they fed. Leaving these great Ichthyosaurian reptiles, I come to another huge creature known by the name of Megalosaurus. This was a gigantic land reptile, constructed somewhat like a kangaroo, with the hind limbs prodigiously large in proportion to the

FIG. 7.—Skeleton of the Pterodactyle. (a) Four free inner digits furnished with terminal claws. (bb) Outer digits sustaining the membranous wings.

fore ones; whether these gigantic hind limbs were made for leaping or for running we do not know. Another saurian is called the Cetiosaurus, meaning the whale-like saurian, of which a fine series of bones is preserved in the Oxford Museum. This creature was evidently built in the heavy type of the whale; at the same time there is no doubt he was a true reptilian animal. In the Museum at Whitby you will

find the remains of several other saurians, including those of a Teleosaurus or crocodile, with a long and narrow head and snout. It so happens that this creature has left a very near relation in the world. Those who have visited India and dipped into the Ganges may know something of the Indian crocodile, known by the name of the Gavial, which is extremely like the Teleosaurus; the latter was doubtless an amphibious creature, equally prepared to take a meal on land or in water, wherever he could best catch one. Still more marvellous is the Pterodactyle, a huge flying reptile whose name merely means that his digits supported wings; and there is no question that this creature was a real flying dragon; probably the only real flying dragon the world ever saw, since those of ancient fables certainly have no existence. When this fellow's wings were outspread they sometimes measured fifteen feet from tip to tip. I think you will say that the Roc was not more likely to alarm poor Sinbad the Sailor than one of these Pterodactyles would have done had it swept past him into the valley of diamonds. When we come to the Wealden beds, which are a local group intermediate between the Oolitic and Cretaceous series, we find these Pterodactyles associated with another wonderful group discovered by my old friend, the late Dr. Mantell, the well-known Sussex geologist. These new forms correspond with the Iguana, a large lizard found at the present day in the West Indies. Here again gigantic size characterised our objects. I remember Mantell showing me, in his collection, a thigh-bone of one of these lizards, which was four feet eight inches long, and of proportionate thickness, even in its imperfect state. Now realise what that means—a lizard with a thigh-bone four feet eight inches long. If you examine the thigh-bone of any living crocodile, you will find it less than a foot in length. From this comparison you will be able to estimate the proportions of these ancient monsters. I have in my own cabinet a fragment of one of these thigh-bones, the dimensions of which when entire must have been even greater than those I have named. Remembering the above facts, I think you will acknowledge the perfect appropriateness of the declaration that the Oolitic and Cretaceous rocks belong to "The Reptilian Age." But we have not yet done with the animals of this period. At Solenhofen, in Bavaria, whence we get our lithographic stones, the skeleton of a bird has lately been found. The notable feature of this bird is seen in his tail, which was long, slender, and tapering, reminding

us of the tail of a lizard. If you examine living birds you will find that, in every case, the bony members of their tails are not only short and compact, but all their tail-feathers are attached to the very last joint of the tail, which is enlarged to allow of their being planted upon it. I repeat that in all living birds the entire series of the tail-feathers is attached solely to the last joint of the tail and to no other; but when we examine this very remarkable fossil bird we find not only a long tail, but each of its bones has one pair of feathers attached to it and no more. There are twenty pairs of true feathers. Such is the earliest form in which indisputable remains of birds present themselves to our notice. I may remind you here that no fragments of the skeletons of the supposed birds which produced the Triassic footsteps of the Connecticut Valley have yet been discovered. Strangely enough, out of the enormous number of these creatures that must have existed, not one solitary fragment of bone, feather, or tooth has been found to give a clue to the nature of the animals that thus left their foot-prints on the sands. If these were birds, of course the one now under our notice came very late into the world; if they were not birds, but two-legged reptiles, as some geologists believe—then this Archæopterix is the oldest bird with which we are acquainted.

I have yet to say a word about the flora of the Oolitic age, which consists either of the Conifers, plants of the pine tribe, or of the remarkable allied group known as Cycads, to which I have already called your attention. Through the Oolitic age we find no trace whatever of the modern types of forest trees; not one solitary leaf, fruit, seed, or fragment of wood of any kind has been obtained that indicates the presence of any other type of arborescent plant than the firs or pines, and these remarkable Cycads. There is no doubt whatever that the characteristic vegetation of this age was Cycadean.

I have already mentioned the discovery of a few teeth of a true mamma near the junction of the Triassic and Oolitic rocks. We meet with other mammalian remains in the Stones-field slate a thin bed belonging to the middle of the Oolitic series. These latter also are either Marsupial, like the Opossums, or Insectivorous, and allied to the Hedgehogs. A third group of these fossils has been found at the upper part of the Oolites in what are called the Purbeck beds. These too are chiefly either Marsupial or Insectivorous—but amongst them are some other

bones that may possibly belong to other classes of mammals, and which require further investigation.

But our time is slipping away, and we must now cross another boundary line and come to the Chalk. The Cretaceous beds are sometimes made up of sands and sometimes of chalk itself; the latter reveals to us a remarkable fact which the great German microscopist, Ehrenberg, was the first to find

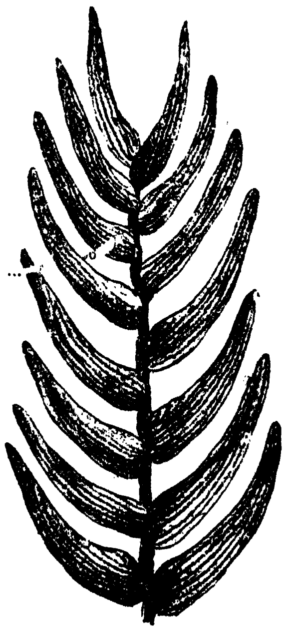


FIG. 8.—Part of a Pinnated Cycadean leaf.

out. If you take a fragment of soft chalk from a Cambridge quarry, you can easily brush it away in water until you resolve it into white mud. Put a little of this mud under the microscope, and you will discover that it is literally made up of the little objects known as Foraminifera.

We have here evidence of the truth of what I told you the

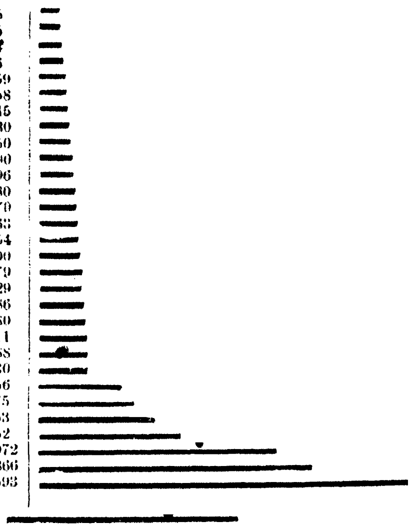
other day, viz., that some limestones, at all events, were not the products of any chemical action operating in the sea, but resulted from the agency of living creatures. As I have already stated, I am perfectly satisfied that the same remark can be made in reference to every limestone rock in existence, excepting those few fresh water Travertins about which I spoke an hour ago, and which are too insignificant in their amount to be taken into consideration when explaining the origin of limestone rocks. The Foraminifera which constitute chalk are very nearly related to the species filling up the bed of the Atlantic, and other seas in many parts of the globe, at the present day. Along with these Foraminifera, we now find an enormous number of organisms of various kinds which we have not met with previously. Thus during the Chalk age, sponges were at least more numerous and varied than at any previous period. At all events the number both of types and of individuals occurring in the Cretaceous strata many times exceeds what we find in any other part of the geological series. We also now find new forms of star-fishes, as well as of the tribe of sea-urchins so common on some parts of our sea coast; but many of these new fossils present forms characteristic of the Chalk age and not found in any other rocks Turning to the Encrimites we again find a change. Most of the old types have gone, and are now represented by the extraordinary creature known as the Marsupite, from *marsupium*, a purse. This is simply an Encrinite without a footstalk. He had no footstalk, at least when grown up, though what he may have had in his babyhood I do not know. Star-fishes are living in the Frith of Clyde, which, in their infantile days, are supported upon a footstalk, but when they grow larger they detach themselves from it and float free. These Marsupites may have done the same. At all events the genus is very characteristic of the Cretaceous rocks. We still find remains of the Pterodactyle, the Mososaurus and the Ichthyosaurus. The Plesiosaurus is no longer there, but it is represented by the Pleiosaurus which much resembles it; these peculiar reptiles survived in diminished numbers, but as we leave the Cretaceous age they pass out of existence, to be replaced, as we shall see in our next lecture, by the modern types of lizards and crocodiles.

I have already spoken of the multiplication in the Cretaceous deposits of forms of shells allied to the Ammonite, and of

TABLE OF THE SPECIFIC GRAVITY OF THE METALS,

SHOWING THE BULKS OF THE DIFFERENT METALS WHICH POSSESS EQUAL WEIGHTS.

Platinum	21·5
Gold	19·5
Uranium	18·4
Tungsten	17·6
Mercury	13·59
Thallium	11·58
Lead	11·45
Palladium	11·30
Silver	10·50
Bismuth	9·90
Copper	8·96
Nickel	8·80
Cadmium	8·70
Molybdenum	8·63
Cobalt	8·54
Manganese	8·00
Iron	7·79
Tin	7·29
Zinc	6·86
Antimony	6·80
Tellurium	6·11
Arsenic	5·88
Vanadium	5·30
Aluminium	2·56
Magnesium	1·75
Calcium	1·58
Rubidium	1·52
Sodium	0·972
Potassium	0·866
Lithium	0·593



Water =

In the last lecture I stated that the mean specific gravity of the earth was 5·6. I also said that we are at a loss in some measure to account for this, because we do not find, so far as we have gone down into the earth, that we come across any of these metals; but we find only substances like granite, which have a specific gravity of only 2·5 or 3. Whether or not some of these heavy metals occur in the interior of the earth, at a lower point than we have yet reached, is, as I reminded you in my last lecture, still a matter of doubt, although the fact of the circulation of truly metallic masses throughout space would rather lead us to believe in the probability of the existence of a similar kind of matter in the earth's interior.

With regard to the elementary bodies, you will observe that on this diagram (see Lecture I, page 8) I have marked fifteen of these elementary substances with a cross. These we term non-metals, as opposed to the remaining forty-nine, to which

we give the name of metals. Some of these non metals are gaseous, such as oxygen and hydrogen, nitrogen and chlorine: some of them are solid, such as carbon. Some of the gases, such as chlorine, can be condensed by great cold, or by exposure to great pressure to liquids, whilst others, such as oxygen, have not been liquefied although exposed to very great pressure.

We may now proceed with our investigation, and ask ourselves, Have we reason to believe that in process of time some or all of these substances may possibly prove capable of being decomposed into other substances? Are these sixty-four substances truly elementary bodies? In this case, of course, we can only argue from analogy, and from what has already taken place. We must look back into the history of our science and inquire if any of the substances which were supposed, up to a certain time, to be elements, have by subsequent research been found to be compound bodies. As an illustration of this, I would bring before you a discovery which was made in the year 1808 by Sir Humphry Davy. In the *Bakerian* lecture for that year, which was read before the Royal Society on November 19, 1807, Davy brought forward a most important discovery which he had just made on the decomposition and composition of the fixed alkalies. This white solid substance which I hold in my hand has long been known as the alkali potash. It is obtained from the ashes of land-plants by boiling the ashes in pots This substance has long been known for its peculiar alkaline properties. Another alkali, obtained from the ashes of sea plants is soda. The term alkali was first applied by the Arabians to the carbonate of soda found in the ashes of sea-weed, and afterwards to the carbonate of potash, obtained by burning land plants, and both these substances were for a long time considered to be identical, whilst the *caustic* alkalies obtained from the *mild* or carbonated alkalies were considered by all chemists to be elementary or simple bodies. Now in the experiment to which I refer, Davy showed that these substances, potash and soda, which up to that time had been supposed to be elementary bodies, are really not so, but are compound substances, that is, bodies which can be split up into two separate things, namely a metal potassium and colourless oxygen gas. I will first read to you a few words giving the gist of Davy's discovery as related by himself in the Philosophical Transactions for 1808. He says:—

"A small piece of pure potash, which had been exposed for a few seconds to the atmosphere so as to give conducting power to the surface, was placed upon an insulated disc of platina connected with the negative side of the battery, of the power of 250 of 6 and 4, in a state of intense activity, and a platina wire communicating with the positive side was brought into contact with the upper surface of the alkali. The whole apparatus was in an open atmosphere. Under these circumstances a vivid action was soon observed to take place. The potash began to fuse at both its points of electrization. There was a violent effervescence at the upper surface; at the lower or negative surface, there was no liberation of elastic fluid; but small globules having a high metallic lustre, and being precisely similar in visible characters to quicksilver, appeared, some of which burnt with explosion and bright flame, as soon as they were formed, and others remained, and were merely tarnished, and finally covered by a white film which formed on their surfaces. These globules, numerous experiments soon showed to be the substance I was in search of, and a peculiar inflammable principle the basis of potash. I found that the platina was in no way connected with the result, except as the medium for exhibiting the electrical powers of decomposition. The phenomenon was also independent of the presence of air. I found that it took place when the alkali was in the vacuum of an exhausted receiver."

I hope to show you this experiment, performed just as Davy did it. I take a piece of white alkali, potash, moisten it by dipping it into water for a moment, and bring it under the influence of a powerful current of electricity, and as soon as I do so you observe that this white substance is decomposed into its two elementary constituents, oxygen and potassium.

The bright luminosity which you notice is due to the burning or combustion of the metal potassium which is liberated at the pole in contact with the zinc of the battery. The white fumes which ascend are the products of the combustion of the potassium which has united with the oxygen of the air with the re-formation of potash.

In order to impress you still more forcibly with this fact, I will throw a small bit of potassium upon water. This body combines with oxygen with such avidity that when I throw it on the water, which you know is a compound of oxygen and hydrogen, the potassium will take hold of the oxygen of the water and liberate the hydrogen, and such heat will be

formed by that liberation of the hydrogen, that we shall see that it takes fire and burns.

Quickly following upon Davy's discovery of the composition of potash came of course the discovery of the composition of soda, and soon after came the decomposition of lime, which Davy also showed was not an elementary body, as had

FIG. 7.

hitherto been believed, but in fact an oxide, being a compound of the metal calcium with oxygen gas.

That hydrogen gas is actually evolved by this action of potassium, and of sodium upon water, I shall be able to show you; for I will collect the gas in this tube, instead of allowing it to burn, and then show you that the colourless gas

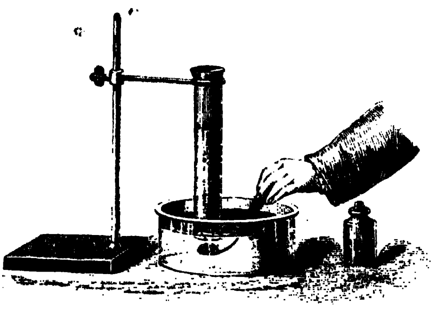


FIG. 8.

thus collected is hydrogen gas. I throw a bit of sodium on the water, and bring it under the surface of the water, so as to collect the hydrogen gas which is evolved in this tube.

I can next show you that the gas is hydrogen, by bringing a flame into contact with it, when it burns with a pale flame, which is of a yellow tint, owing to the presence of soda.

I have here a beautiful specimen of the metal sodium, the substance which is the metallic basis of soda. Here again this beautiful, bright, shining metal which we know as magnesium is the metallic basis of the earth magnesia, for this earth can also be split up into a metal and into oxygen gas. When I burn this metal you see that we get a bright white light which is due to the combustion of the magnesium and its combination with the oxygen gas of the air. The white powder which you see falling down is the oxide of the metal, formed by the union of the metal with oxygen.

Since Davy's time several other substances supposed to be elementary have been proved to be compounds. These have been chiefly among the rarer elementary bodies. I have here the means of explaining one of these interesting cases. This cube we will suppose for the moment to be a metal to which the name of "vanadium" is given. It was believed that this body was really a metal; but a few years ago it was found that two different things could be obtained from this, viz., a true metal and oxygen gas; so that the substance which was considered to be an element really proved to be a compound, with oxygen inside it, as it were. I may illustrate this to you by taking out from the inside of this green box of supposed metal, this red box labelled oxygen, which had hitherto escaped our observation because it was hidden inside the green box. Here you see a list of four substances, titanium, uranium, niobium, and vanadium, all rare bodies which were believed by the discoverers to be metals, but which have since been shown to be compound bodies.

TITANIUM.	URANIUM.	NIOBIUM.	VANADIUM.
Wollaston ... 1823 Wöhler... ... 1849	Klaproth ... 1789 Peligot... ... 1849	Hatchett ... 1801 Rose ... 1842-64 Marignac ... 1865	Sefström and Berzelius... 1831 Roscoe... ... 1867

Then the question arises—Looking back at the history of our science, as we have been doing, is it possible that any of the substances which we now speak of as elements, may hereafter turn out to be compounds? With regard to this, our conclusions must be conjectural, but we may remember that certain of these elementary bodies possess common or analogous properties—certain family likenesses. I will select one out of many examples of elementary groups with

which we are acquainted. We have here three elementary bodies: one of them, chlorine, is a gas; another, bromine, is a liquid; and the third, iodine, is this black solid body. The bromine and iodine can be converted by heat into gases, each of which is distinguished by its peculiar colour. Here you see the beautiful purple colour of iodine gas, here the dark reddish-brown colour of bromine gas, compared with a beautiful greenish-yellow colour of chlorine. These substances, as I said, resemble one another very closely in their properties. I will next show you that this is the case. I will take a small quantity of iodine, a small quantity of bromine, and a cylinder filled with chlorine, and I will bring into contact with each of these substances a small piece of the element phosphorus. You will then see that each of these substances exhibits the same properties with regard to the phosphorus with which each of the three elements combines with evolution of light and heat. This indicates, so far as phosphorus is concerned, that these three substances have similar properties. The phosphorus, you see, takes fire and is burning in the chlorine gas. The same thing will take place when I bring a drop or two of bromine into contact with the phosphorus. You see that the phosphorus has taken fire and is burning. I will now show you that the same result occurs with the phosphorus and the iodine.

In other respects, too, these three bodies exhibit remarkable and as yet unexplained analogies. Bromine, both in its chemical and physical characters, stands half-way between chlorine and iodine. In its volatility, in its specific gravity, as well as in its power of chemical union, bromine is a sort of half-way house between the other two. In like manner the number representing the weight with which bromine enters into chemical combination is almost exactly the mean between the similar numbers of chlorine and iodine. Thus whilst 35·5 and 127 are the combining weights of chlorine and iodine respectively, 80 is the combining weight of bromine, the arithmetic mean of the two other numbers being 81.

Now, up to the present time this solid iodine, this liquid bromine, and this gaseous chlorine are elementary substances, because we have never succeeded in getting the one from the other, or in splitting any one of these into two different things. We have as yet not succeeded in turning iodine and chlorine into bromine. But no one who is acquainted with the properties of these substances would be surprised to learn

that bromine had been shown to be in some way connected with chlorine and with iodine; and therefore although we cannot prove it, yet from studying their properties and knowing the nature of the several elements, modern chemists do not consider the problem of the transmutation of the elements to be an absurd one, although we may look to a different kind of solution of the question from that aimed at by the old alchemists.

The next question which attracts our attention is also one of great interest—the question, namely, whether these sixty-four elementary bodies make up the sum total of the elementary constituents of our globe, or whether, in all probability there are other elements existing which have up to the present time eluded our grasp. Here, again, we can only argue from analogy. We can only look back at the history of our subject and see whether new elementary bodies have been discovered, and then ask ourselves is it likely that other new ones still remain unknown to us, but which will be revealed by subsequent investigation?

I mentioned in the last lecture that during the lifetime of Lavoisier only seventeen substances were known to exist as elementary bodies; whilst since his time discoveries of new elementary bodies have been made until the number known to us is sixty-four.

In what way have these new elementary bodies been discovered, and in what way may we look forward to the discovery of new substances now unknown? I will illustrate this to you by one or two simple experiments, and thus indicate to you how in the last few years new elements have been found.

In the year 1860 Professor Bunsen, one of the greatest of living chemists, was busy investigating the properties of a peculiar mineral water which springs out at Baden-Baden in Germany, and having collected a large quantity of the residue from this water, he discovered in it the existence of two new alkaline metals, which up to that time had been overlooked. These two new alkaline metals were discovered by Bunsen by the help of a new method of investigation, a method which I dare say many of you are acquainted with, but the principles of which I will briefly allude to—the method of spectrum analysis.

It has been long known that when certain substances are brought into a colourless flame, such as you see here, they

have the power of imparting to the flame a peculiar colour; but it has only recently been observed that when these coloured rays are examined more accurately than we can do simply by the naked eye, when this beautiful purple flame which you see burning here is examined by means of a prism in the instrument termed the spectroscope, one of which you see on the table (Fig. 10), we have the means of detecting the presence of small quantities of matter which have hitherto altogether eluded our grasp.

This spectroscope consists of a prism (*a*. Fig. 10) fixed upon

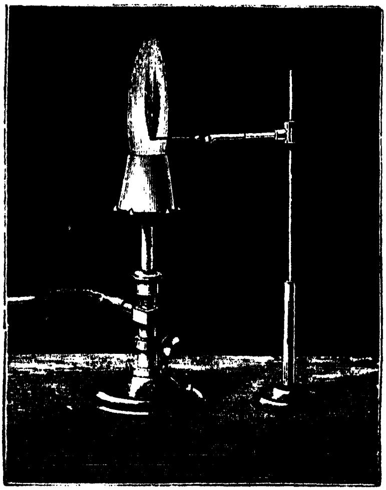
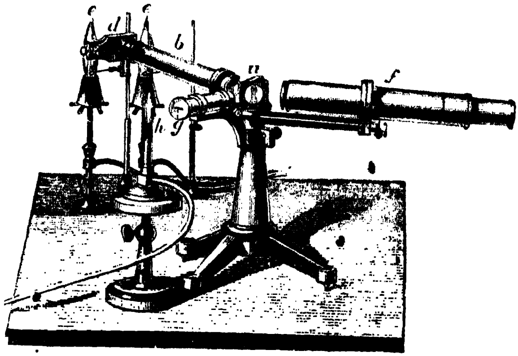


FIG. 9.

a firm iron stand, and a tube (*b*) carrying the slit, seen on an enlarged scale in Fig. 10 (*d*), through which the rays from the coloured flame (*é* and *e*) fall upon the prism being rendered parallel by passing through a lens. The light having passed through the prism, and having been refracted or split up into its constituents, the differently coloured rays are received by the telescope (*f*) and the image magnified before reaching the eye. The rays from each flame are made to pass into the telescope (*f*), one set through the uncovered half of the slit, the other by reflection from the sides of the small prism (*e*),

through the lower half; thus bringing the two spectra into the field of view at once, so as to be able to make any wished-for comparison of the lines.

In this way Bunsen was enabled to prove that in the residue from the alkaline deposits in the waters of Baden-Baden there was present a substance not hitherto observed, and to this substance he gave the name of rubidium, from *rubidus*, dark red, whilst to the other alkaline metal he gave the name cæsium, from *cæsius*, sky colour. I will next show you the spectra of these metals on the screen. I have here the means of producing the bright light of the electric arc (Fig. 11), and by casting these rays first through the slit B, then through the lens D, and lastly through the two prisms E and E′, we



obtain on the screen the beautiful bright band, which you see exhibits all the rays of colour from red to violet, and is therefore called a continuous spectrum.

This is produced by white-hot carbon poles, and any white-hot solid body will produce the same effect. If, however, instead of allowing the light to proceed from the carbon poles, I examine the rays which come off from the purple-coloured rubidium flame which is here burning, I obtain a totally different effect in the spectrum, for I produce what is known as a broken spectrum; that is to say, instead of having an unbroken succession of colours, I have a series of bright lines which are different for every one of the sixty-four elementary bodies. The bright bands which were observed by Bunsen in the

Baden-Baden mineral water were different from any which had hitherto been noticed, and were produced by the presence of a new element.

I will now bring on to the carbon pole a small quantity of

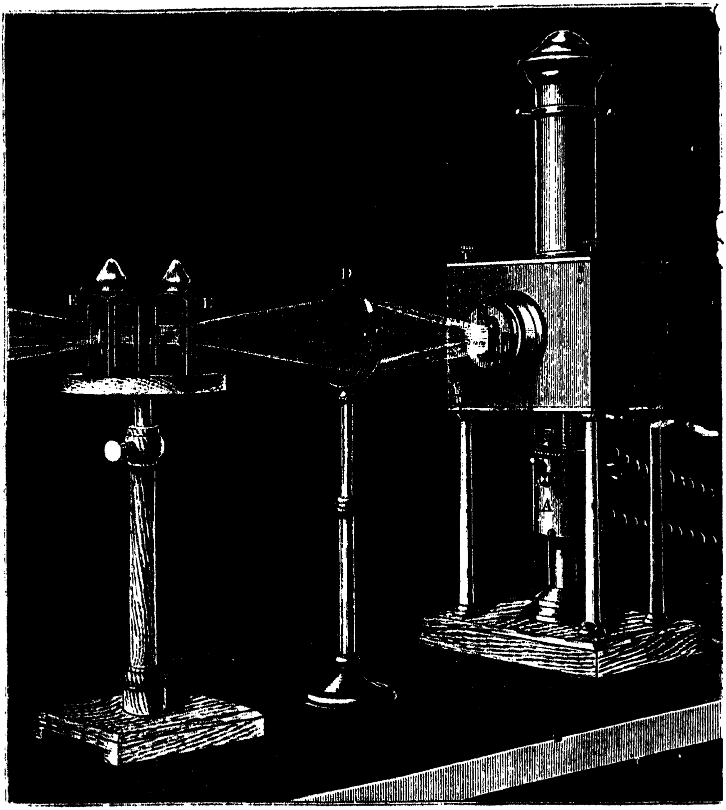


FIG. 11.

a rubidium salt, and you will then see the effect which this is capable of producing. You will notice that we have a spectrum totally different from that which we have had before. Here we get a distinct series of bands, one in the red being

very characteristic, and these are indicative of the presence of rubidium, and are produced by no other known substance.

A year after Bunsen's discovery, Mr. Crookes was able to prove, by means of spectrum analysis, the existence of a third substance, to which he gave the name of thallium. I can now show you the grounds which led Mr. Crookes to assert the existence of a new metal, which had hitherto been overlooked. You see on the screen a green band, which is given by no other substance but thallium.

A fourth metal was discovered by the same means, a metal to which the name of indium was given, because it exhibits two very beautiful lines in the indigo. Here you see the bright lines characteristic of this metal, an extremely rare substance, discovered by Messrs. Reich and Richter. No other substance known will produce these peculiar bands of indigo-coloured light.

A fifth new element has quite recently been discovered by means of spectrum analysis. To this body its discoverer, M. Lecoq de Boisbaudran, has given the name of gallium. Unfortunately this substance has hitherto been found in such minute quantities, that I have none to show you.

From what I have said you will conclude this instrument, the spectroscope, has become one of the chemist's most potent assistants, and that we have only to go on examining by its aid the composition of terrestrial matter with still greater care, and apply to the examination means of still greater accuracy than we have hitherto done, in order to discover a still larger number of elements, and thus to add to the stones of which the edifice of our science is constructed.

The question next arises—Have we any evidence respecting the chemical composition of the other heavenly bodies? The most evident means which we have of examining the composition of matter existing in space beyond our earth, is by analysing those singular and interesting bodies which fall from time to time on the earth's surface, namely, the meteorites, or falling stars, as they are commonly termed. I have in my hand such a meteoric mass. This piece of stone differs both in appearance and physical characteristics from ordinary rock, such as the earth is composed of. If we cut into these meteorites we find that they are made up either of masses of bright shining metal, chiefly metallic iron, or of stony matter interspersed with little nodules, or spots of metal. But although their physical characteristics are totally different

from those which belong to terrestrial matter, yet, when we come to examine their chemical characteristics, we find that these are altogether the same as the chemical characteristics of terrestrial matter, in other words, when we come to analyse these meteorites, we find that they really consist of the same elementary bodies as we find compose the mass of the solid earth's crust, and up to the present time, no new elementary body has been found on any one of these meteorites.

ANALYSES OF METALLIC METEORITES.

	Analyst.							
	Smith.	Field.	Forch-hammer.	Uricoe-chea.	Uricoe-chea.	Pugh.	Pugh.	Berge-mann.
Iron	85·54	87·80	93·69	81·20	90·40	90·43	87·89	85·42
Nickel	8·55	11·88	1·56	15·09	5·02	7·62	9·35	9·73
Cobalt	0·61		0·25	2·54	0·04	0·72	1·07	0·44
Copper	0·03	—	0·15	—	trace	0·03	trace	0·03
Tin	—	—	—					
Manganese	—	—	—	—	—	—	0·20	
Magnesia	2·04	—	—	—	—	—	—	—
Chromic oxide	0·21	—	—	—	—	—	—	—
Sulphur	—	—	0·67		trace	0·03	—	0·84
Silicon	—	—	0·38	—	—			
Silica	3·02	—	—			—	—	—
Phosphorus	0·12	0·30	0·18	0·09	0·16	0·15	0·62	—
Phosphide of Iron and Nickel	—	—	—		2·99	0·56	0·34	1·05
Carbide of Iron	—	—	—	—	—		—	0·33
Chrome Iron	—	—	—	—		—	—	1·48
Admixed Minerals ...	—	—			1·11	0·34	0·22	—
Carbon	—	—	1·69	—	—			
Residue		—	—	0·97		—	—	—
	100·12	99·98	98·57	99·89	99·72	99·88	99·69	99·32

Here we have a list of the constituents of some of the best known meteorites; you see that they contain iron, nickel, cobalt, copper, tin, manganese, magnesium, sulphur, phosphorus, and carbon. These are all substances which we know of as building up the solid mass of the earth, and we, therefore, come to the conclusion that the particular kinds of matter which we know to exist on our earth, are also found in the masses which circulate in space and fall down upon the earth, so that the materials of which the universe is built up, so far as our evidence reaches, would appear to be homogeneous, and not different in each different heavenly body. Nor is it indeed impossible that the earth's interior mass may even

their final disappearance, along with the Belemnite, at this epoch.

But there are other remarkable vertebrate creatures yet requiring our attention. Two diagrams before you represent the lower jaws of two species of bird that have been discovered in the western regions of North America, by Professor Marsh, one of the first naturalists of America, who has found, at least, thirteen species of fossil birds in the rocks of ths Cretaceous age. Some of these were met with on the Atlantic coast, and others in the far district of Colorado; the feature that is so remarkable about some of them, is that their beaks are furnished with rows of teeth as regular and definite as are those of any reptiles. This is a marvellous and unexpected fact. We have no bird with teeth at the present day. Anatomists of the evolutionist school naturally refer to these birds as indicating a transition state between reptilian forms and modern types of bird organisation, and it is unquestionably true that they have very strong reasons for arriving at this conclusion. It is unquestionable that these objects are true teeth, each having a fang at its base, and having the upper part of each tooth covered with true enamel. Then the teeth are sometimes planted in a row of distinct sockets, whilst in others they are fixed in a groove, which shows a gradual approximation towards the development of sockets. Teeth like these must have belonged to carnivorous creatures. The two birds to which I am referring were both aquatic. One of them was about the size of a pigeon; but the other was a large diver, measuring about six feet from the tip of the beak to the end of the toes. It was a powerful bird, but, like the living Penguin, was unable to fly. Its wings were merely rudimentary ones. The supposition that this bird represents a form intermediate between the bird and the reptile, is further sustained by the circumstance, that, at the extremity of the upper jaw of this species, there were no teeth, but the jaw appears to have terminated in a horny beak. So that you have here combined the reptilian tooth with the beak of an ordinary bird; according to the evolutionists, as time went on, the beak grew bigger and the teeth grew less, until the latter finally disappeared. Thus there was handed down to future ages the race of feathered descendants which we see around us at the present day.

An extraordinary change came over the vegetation of the

world during the Cretaceous age ; a change which not only affected the plants themselves, but the results of which reveal some remarkable phenomena connected with the distribution of heat and cold over the earth. In both the lower and upper parts of this Cretaceous series, we now find, for the first time, the representatives of living plants belonging to the flowering tribes comprehended under the name of Dicotyledons, and many of which are closely related to trees now flourishing in the forests of the world. We now come upon species of fig-tree, oak, beech, poplar, myrtle, willow, and magnolia, along with pines, ferns, and a host of other allied plants. The oldest of these Dicotyledonous plants with which we are acquainted is a species of poplar. We have seen that up to the commencement of the Cretaceous epoch, the only known plants have been pines, Cycads, and the various forms of cryptogamic vegetation ; but recent discoveries have brought to light such a multitude of the higher forms of vegetation, from various parts of the world, that my two friends, Professor Heer, of Zurich, and Professor Lesquereux, of Columbus, United States, who are investigating these plants, run a fair risk of being overwhelmed by the multitude of specimens accumulating in their hands.

The climatal features to which I referred are quite as remarkable as the rapidity with which these new forms of vegetation multiplied and spread over the earth. Many of the specimens of this new vegetation have been brought to us from Greenland, a country which is now covered with ice, and where not a stick or leaf of a living tree will now grow ; where, in fact, there is no vegetative life excepting the herbaceous plants that spring up during the brief summer. And yet in the age of which I am speaking, Greenland possessed magnificent forests, similar in many respects to those which now flourish in the warm Southern States of North America.

If you hunt through the forests of England and of midland Europe, you discover no species of magnolia or myrtle, fig-tree or Cycad, Tree-fern or Oleander, yet all these flourished in the ancient forests of Greenland. Some stupendous changes have evidently been wrought in the world since those days. It is very clear that the distribution of snow and ice was very different then from what it is now. Whether the earth's axis has got a twist, or whether in those days the globe was

whirling through some warmer parts of space than now surrounds us, is not easy to determine. The probabilities are against the idea of any change in the poles of the earth; but something strange must have occurred since the time when not only forests of magnificent trees overspread that Greenland continent, but when tropical genera of ferns, such as the Gleicheniæ, flourished as an undergrowth in even greater numbers than is the case with these ferns in tropical forests at the present day.

THE SUCCESSION OF LIFE ON THE EARTH.

LECTURE III.

The physical and vital agencies which modified the crust of the earth and its inhabitants through the long periods which occupied our attention in my first two Lectures, did not cease their action at the close of the Cretaceous age. They are producing similar effects now to those which they caused in the beginning of time, and probably with undiminished energy. But for a long period the effect produced by those agencies, subsequently to the Cretaceous age, were very ill understood. Until the early part of the present century what we now call the Tertiary rocks were almost altogether neglected. Baron Cuvier—one of the greatest of European naturalists—first showed the world that the Tertiary deposits in the neighbourhood of Paris contained the remains of strange and extinct animals. This discovery opened the eyes of geologists to the fact that there existed a series of superficial deposits, which eminently merited any amount of labour that might be bestowed upon them.

The important discoveries of Cuvier made a powerful impression on that great geologist whose death we had so lately to deplore—I mean Sir Charles Lyell. Lyell undertook the study of these neglected Tertiary beds. He endeavoured, and with a large amount of success, to reduce them to order by making use of the fossil shells which they contain. I may observe here that in all probability, if we except some Foraminiferous creatures of low organization, no one species either of plant or animal that lived previous to the close of the Chalk age, survived that period. Except one doubtful shell all the species found in the Mezozoic strata became extinct. None of them are to be found in any of the Tertiary strata. You will understand, however, the limitation with which I make this utterance. If the doctrine of evolution be true we are all descendants of species that lived prior to the Chalk age.

But naturalists have hitherto applied the term "species" to individuals, the probability of whose descent from common parents is indicated, by the identity of their organization; groups of organisms are regarded, as being of the same species, when their individual members, are more like one another than they are like any other objects. The term species being thus defined, it becomes true, that all the Tertiary species are different from those which lived previous to the close of the Cretaceous age. Still less could any of the latter be identified with such as are now living on the earth. But when we cross the boundary line that separates the Cretaceous rocks from the Tertiary deposits, we begin to find the fossil remains of species that are still living. Lyell made use of this fact, and based upon it his classification of the Tertiary strata that we are about to study. He found that in the oldest of these Tertiary beds there was not more than about three and a half per cent. of recent shells in every hundred fossil species that he examined. Therefore he threw these oldest beds into one group, to which he gave the name of Eocene—a term signifying the dawn of recent life. In strata of newer age he found something like thirty-five per cent of living shells, associated with sixty-five per cent. of extinct ones. To this group of deposits he gave the name of Miocene—or less recent. Then when he came to other deposits of still more modern date, he found that the proportion varied from forty or fifty per cent. up to very nearly 100 per cent.; and to these he gave the name of Pliocene, or more recent.

The deposits to which Cuvier's attention was chiefly directed belonged to the Eocene period of life. I need not dwell upon the vast multitudes of shells that were found in them, though many of these were peculiar, including numerous genera not met with in the older rocks but which are amongst the most common of those now living. We thus learn that on crossing from the Cretaceous to the Tertiary beds even the molluscan forms of life underwent a sudden change. This is equally true of those which ceased to exist and of those which now appear for the first time. I have already pointed out in how marked a manner this statement applies to the Cephalopoda, or animals allied to the Nautilus and cuttle-fishes.

In our own country these Eocene strata are only found in the south-east of England, and especially in the neighbourhood of London and the Isle of Wight. In them we find the remains of reptiles, birds, and mammals. But the Ichthyosaurus and its

companions are now replaced by the crocodile and the serpent. The latter creatures were as large as the tropical Boa-constrictors of the present day, and amongst them there was, according to Owen, a huge and veritable sea-serpent—though not having yet caught *the* great sea-serpent, I am not quite clear as to what his anatomical characteristics are. Then we have numerous turtles—rather smaller than the recent ones seen at aldermanic feasts. Fishes of many varieties now abound. The modern types which first presented themselves in the Chalk age now become the prevailing forms—replacing the Mezozoic and Palæozoic Ganoids which, though still represented become comparatively rare. Figure 9 represents the

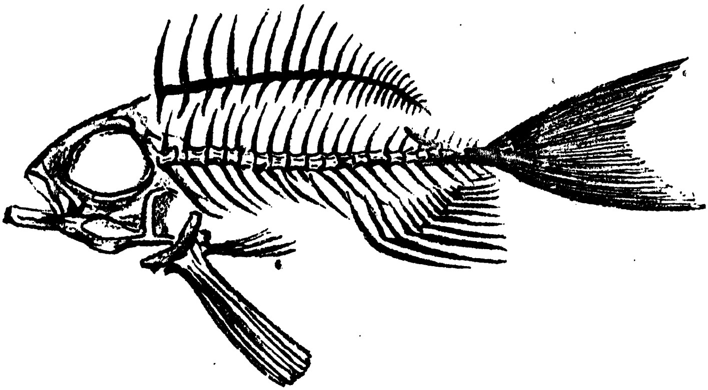


FIG. 9.—Skeleton of a perch of the Eocene period, displaying the homocercal tail.

skeleton of a species of perch, from the slate-quarries of Glarus in Switzerland. This skeleton exhibits the *homocercal* tail, to which reference was made in a previous lecture. At the latter part of the Cretaceous age we find for the first time fishes allied to the salmon, perch, and many other forms living in our seas and rivers at the present time. You will probably remember I told you that no solitary fragment of those modern types of fishes to which Agassiz gave the name of Cycloids and Ctenoids, from peculiarities seen in the forms of their rounded scales, had hitherto been met with in rocks older than the Cretaceous series; but towards the upper part of that group they begin to appear, and when we cross the

boundary and come to the Tertiary deposits these fishes crowd upon us in great numbers. Sharks of huge size were also common, as is shown by their numerous teeth preserved in the Eocene beds. But it is when we come to the Mammals, especially to those first discovered by Cuvier, that we are most strongly reminded of the changes which have overtaken the world's fauna.

When Cuvier first discovered the bones of these creatures he showed to the scientific world, that, from the study of a limited number of bones, he could reproduce, with considerable probability, the entire animal. He did this by means of what he designated the law of co-relation, or, in other words, the mutual dependence of parts upon each other. That such restorations are possible within defined limits is doubtless true; but when I hear of their being accomplished by the examination of a fragment of bone or of a tooth, I can merely smile at the world's credulity. If the combination of organs in the extinct animals had exactly corresponded with what we see in living ones, such feats of anatomical legerdemain might have been possible. But no man only possessing the skull of a Pterodactyle would have given to the animal the wings of a bat; neither would acquaintance with the skeleton of the body of Marsh's large Diver have led its discoverer to connect with it jaws full of enamelled teeth.

The chief quadrupeds which Cuvier found in these deposits were of two types; one of these was a heavy creature, somewhat like the pig; the other was an animal of much lighter construction. Cuvier showed, what we have no doubt now is perfectly true, that these were Mammalian animals, very closely allied to the Tapirs of which herds now roam through the South American forests.

The Tapir is a hog-like creature, but nevertheless not a true pig. It had its upper lip prolonged into a sort of proboscis, which was also the case with the Palæotherium. But Cuvier's other discovery, the Anoplotherium, was a creature of a much more graceful structure, and approached somewhat nearer to the Antelopes. The remains of these creatures are found not only at various points on the continent of Europe, but in England. Another Eocene mammal is the Hyænodon, which was probably one of the oldest of true carnivorous mammals.

We now meet with another well known group of animals not found in older strata—I mean the whales. In this lowest Eocene deposit there has been found, especially in the United

States of America, a huge whale furnished with very remarkable teeth, and known by the name of the Zeuglodon, and we know for a certainty that some of these Zeuglodons were fully seventy feet in length. Thus you see that though the giant Ichthyosaurus and other allied aquatic reptiles have disappeared from the sea, other huge marine creatures have taken their place, though of an entirely different class.

The general conclusion to which we are brought by the study of the animals found in these Eocene deposits is that at the period in which they were accumulated, the animal life on the globe was of a somewhat tropical character. This conclusion is further confirmed by the study of the plants of that age. We now find tropical palms, and associated

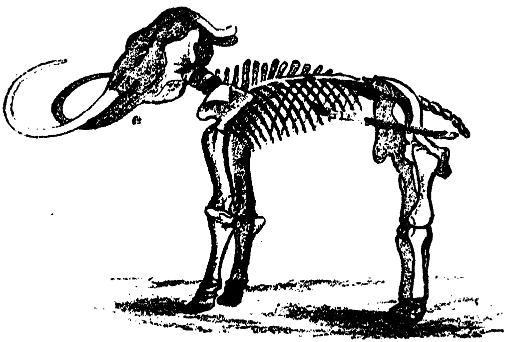


FIG. 10 — Skeleton of the Mammoth.

with them we have a large number of other plants, the seeds and fruits of which are yet preserved, all indicating the same general fact, namely, that the temperature at the period in question was very high.

But we must now cross another threshold and enter upon the Miocene age—in which we discover a marvellous outburst of that animal life, living forms of which now constitute so conspicuous a feature in the forests of India and Africa. We have probably no trace of these Miocene deposits in England; but when we cross to the Continent, we find them here and there in detached patches. As we proceed to the flanks of the Alps they crop up in larger masses, and an enormous range of them runs along the southern flank of the Himalayan

hills; these deposits are rich beyond any precedent in the remains of gigantic animals very similar to some now living. This remark applies to the Miocene deposits in various parts of the old and new world. We have now the Mammoth and the Mastodon—huge forms of Elephants; then we have the Hippopotamus, Rhinoceros, Bear, Hyæna, Monkey, Giraffe, Camel, and Deer of numerous forms. The Dinotherium was a huge elephantine animal but with two tusks projecting downwards from the lower jaw. The Sivatherium found in India, was a stag-like ruminant with two pairs of horns, and associated with it was a gigantic Tortoise eighteen feet long! I have said enough to show how marvellous and rapid has been the outburst of new forms of animal life, contrasted with its slow development in previous ages.

In dealing with the question of evolution we have carefully to consider the facts which I am now briefly enumerating. Recollect how extremely insignificant the thickness of the deposits that we are speaking of is compared with those of earlier date. The entire series of Tertiary beds is only represented by a very thin line even in any large section of the stratified rocks drawn to one scale. Yet, as I have already shown, the thickness of a series of deposits constitutes our best standard, imperfect though it be, for measuring the time which those deposits occupied in their accumulation. Remember then that in the lowermost part of the Tertiary series we have scarcely any of these mammals. The few found in beds of the Eocene period are but scanty representatives of the group; but when we turn a corner, it appears as if some great magician had waved his wand and, in response to the magic summons, life of the most varied character, and in forms most dissimilar from what immediately preceded, flash into existence.

The evolutionist has to explain these unprecedented phenomena, and to ascertain, if he can, how it is that this development of animal forms has proceeded so slowly through millions of years, and then at a very late period, as if in preparation for man's advent upon the earth, it should suddenly advance with such amazing rapidity. I contend stoutly that however numerous may be the facts that sustain the doctrine of evolution (and I am prepared to admit that there are many that do so in a remarkable manner) this unexplained outburst of new life, demands the recognition of some factor not hitherto admitted into the calculations of the evolutionist school.

Before we finally leave the Miocene age I would call your attention to the imperfect knowledge, not only of fossils, but of anatomy, which prevailed amongst naturalists in the early part of the last century. Scheuchzer, one of the most eminent naturalists of his day, obtained a skeleton of a large newt or Salamander from a quarry at Œningen, whence many similar skeletons have since been obtained. This he described, in more than one work, as the skeleton of a man who had been drowned in the Noachian Deluge. The fact that this Salamander rejoiced in the possession of a tail seems to have constituted no difficulty in the way of this primitive geologist. Both in size and form the Œningen reptile approaches very closely to a living Japanese species.

Leaving the Miocene we come to the Pliocene period, which has left its memorials, in the south-eastern counties of our own

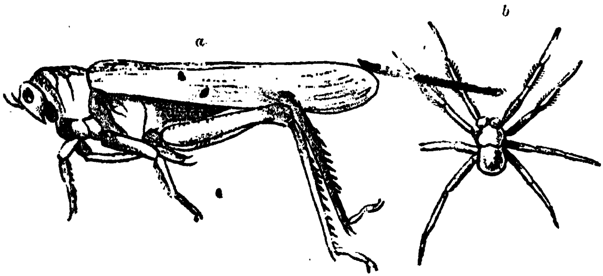


FIG. 11.—(a) Œdipoda Haidingeri, a grasshopper from the Miocene beds of Radoboj in Croatia (after Heer). (b) Schellenbergia rotundata. A Miocene spider from Œningen in Switzerland (after Heer).

country in what is called the Crag of Suffolk, as well as in other parts of the world; we still find scattered amongst these deposits the remains of most of the Miocene Mammalia which continued to flourish, though the climate became much more temperate than it formerly was.

The detached Pliocene deposits are doubtless of various ages —but throughout the entire series we find numerous, still living, species either of marine or fresh-water shells; but curious changes have occurred in some of these species. Some which were very common in the Pliocene seas are now rare on our coasts, whilst with others the reverse is the case. There is no doubt that these shells indicate a change from tropical to temperate conditions. Nevertheless some of the

marine objects continue to be very remarkable. This is especially the case with the sharks, of which the fossil teeth are very numerous in what are called the Crag deposits. Many of these teeth are of enormous size. Comparing them with those of large living sharks, and assuming that the magnitude of the jaws increased in the same ratio as the teeth, we may fairly conclude that some of these fishes must have been able to open a mouth wide enough to take in the contents of a London Omnibus at one bite. Along with remains of the shark we now find bones of the true whale. These are not the Zeuglodons of the Eocene age, but whales of the modern type.

As the Tertiary age advanced we discover that the living types of vegetation became more and more abundant. You will recollect I called your attention to the fact that even at the close of the Cretaceous age poplars, myrtles, magnolias, and a whole host of other Dicotyledonous trees, belonging to warmer climes than ours, had begun to make their appearance on the earth. As the Miocene age passed by we find that the genera and species of these trees multiplied quite as rapidly as the quadrupeds. We further learn from the fossil plants that the distribution of heat and cold on the earth continued to be very different from what it now is. Thus, even in the Miocene age, parts at least of the ice-clad continent of Greenland were still clothed with rich semi-tropical forests in which district forms of plants were almost as abundant as they were at the close of the Cretaceous period. When those northern regions assumed their present condition we have yet to learn; but the change was probably coæval with the similar ones which affected the entire northern hemisphere after the close of the Pliocene epoch.

An age arrived when the semi-tropical conditions that prevailed in the periods of which I have been speaking, gradually yielded to influences of a more chilling character. Ice and snow began to creep southwards from the Arctic regions, until at last there arrived a time, now known as the Glacial age, in which the greater part of the northern hemisphere was covered with ice and snow, much in the way that Greenland is so clothed at the present time. How long this condition of things continued we do not know; but you will readily understand that such a physical change would necessarily produce great alterations in the life of the period; and geology affords us proof that this was the case. We now find the Reindeer

feeding at the foot of the Alps; its remains, along with those of the Musk ox, supplies of which animal, you remember, made a welcome addition to the scanty larder of the late

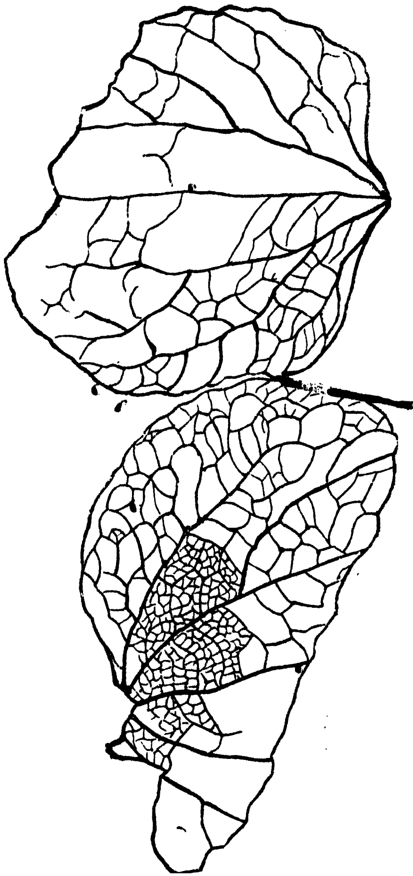


FIG. 12.—Leaves of a Miocene species of Poplar (*Populus arctica*) from Greenland (after Heer).

Arctic explorers, occur over the whole of northern and temperate Europe, including our own country. The Glutton, another Arctic animal, has also been found in a fossil state in some of these glacial deposits. To give even an outline of the history

of this age would require a dozen lectures in order to do the subject justice. I should have to unfold to you the history of those wonderful ossiferous caverns which have been found in various parts of the world, and the investigations of which have been productive of such remarkable results. But time will not allow me to dwell upon these matters, beyond pointing out to you some of the more characteristic phenomena. On studying the Tertiary age generally, we cannot fail to see how much the world changed in one point as it grew older. At those periods which we examined in the two first lectures, we have every reason for supposing that animal and vegetable life presented a far greater uniformity than now from the Arctic to the Antarctic zones. Thus we find that the plants of the Coal measures of Australia are almost identical with those found in the Coal measures of Greenland and Spitzbergen, and the remark is equally true of the Coal measures of the intermediate zones. As the world grew older, and as we approach nearer to recent times, we find gradually springing up a tendency to local differences in the life characterising the different geographical areas; but at length we reach a period in which every country seems to have had its own distinctive animals, just as it has now. If I take you at the present day to the woods of South America, what do we find there? Amongst other things, numerous small Sloths hanging upon the trees, and feeding upon their leaves. In the Post-pliocene age Sloths were common in the same region, but they were as big as oxen, and consequently altogether unfitted for climbing up trees; but, as Professor Owen has shown, they were fitted for pulling the trees down. The same American province now abounds in Armadillos, which burrow into the soft soil as rabbits do in our own warrens: but amongst these we find the remains of an enormous extinct Armadillo, which must have been as big as a carrier's covered van. He was certainly above nine feet long from snout to tail.

If we cross to New Zealand, what do we find there? At the present time we have no Mammalia in New Zealand other than a rat and a bat. This fact possibly explains why the old New Zealanders were cannibal; if you realise that they had no domesticated animals such as we have, and that the only chance of getting meat was to eat their enemies, we can scarcely wonder that a savage race should see no harm in doing so. There has been found along with this rat and bat, the

Apteryx, a small species of wingless bird, about the size of a Cochin-China fowl. This bird belonged to the same group as the Cassowaries of Australia and New Britain. In the later Post-pliocene days, birds of this class were extremely numerous in New Zealand; but instead of resembling the living Apteryx in size, they were often larger than any living ostriches, some of them being fully ten feet high. Their bones are now scattered abundantly over the length and breadth of New Zealand; and it is clear that their extinction was due to the same agencies as destroyed the Dodo of the Mauritius. They were eaten by the natives as long as any remained; and when this game was no longer available, the New Zealander would be more likely than ever to eat his fellow-men.

A species allied to these New Zealand Moas, as they are called, has been found in Madagascar; we have also got the eggs, and it is calculated that one of them would contain about 148 modern hen's eggs. Thus you see that both in South America and New Zealand the animals that still live there are the representatives of others which lived in the same countries during a bygone age; but the living forms are the dwarfed representatives of the older giant race. In Australia the living animals are chiefly of the Kangaroo type, of which there are enormous numbers, both as regards individuals and species; and the remarks I made about New Zealand apply equally to Australia. We find in the caves of Australia fossil Kangaroos of the Post-pliocene age, and they were as much larger than those now living as the Megatheria and Moas of South America and New Zealand were larger than the Sloths and wingless birds of the present time. The point which I urge upon your attention is this—that the geographical distribution of animals at the present day does not differ, in many cases, from that which characterised the later geological ages. In the northern hemisphere this is true with an important limitation. We have already seen how during the Tertiary period the numerous Mammoths and their huge companions spread over the entire hemisphere. Then came the Ice age, which drove these creatures southwards, though we have evidence that both the Mammoth and the Rhinoceros were clothed with a covering of wool and hair, enabling them to endure a colder climate than can be borne by their modern representatives. At the same time they never were Arctic animals. They must have had vegetation upon which they could browze, and their companion, the Hippopotamus, must

have had unfrozen rivers in which it could swim. After the great invasion of ice passed away many of these animals returned to their old haunts; but they gradually disappeared one by one, leaving behind them only the wolf, the bear, the elk, and the deer to represent them in the temperate portions of the northern hemisphere at the present day—the larger forms of animals which formerly were their companions, and characteristic of the same great zoological province, having now retreated to the forests of Southern Asia.

After a period of unknown duration the ice began to recede northwards owing to a return of more genial suns. There is much difference of opinion amongst geologists as to the detailed succession of events during this age of milder temperature, but it is obvious that a struggle between sun and frost continued for a long period. There is much reason for supposing that after the first great Glacial age, the ice so far disappeared as to leave extensive tracts of land over which the Pre-glacial animals spread themselves, and that this very variable "Inter-glacial" period was succeeded by a return of the ice-sheet which again overspread parts of the temperate zone. Be this as it may, the ice-sheet finally disappeared, but its remnants lingered in the shape of numerous glaciers which long continued to occupy the gorges of our mountainous regions. During this later time the Mammoth and many of its Pre-glacial companions still roamed to and fro amongst our lower valleys and over our wide plains. At that time our island was not only united to the continent of Europe, but, in all probability, stretched far away southward and westward into the Atlantic. So that the ancient Europeo-Asiatic fauna was also the fauna of what is now Great Britain. The way in which the bones of southern forms of Mammalian life have become intermingled in caves and other Post-pliocene deposits makes their history a difficult one to render intelligible. This much however is certain. One by one these huge Mammals passed away from these latitudes. In all probability the latest survivor of the vast herds which once covered central Europe, but which do so no longer, was the noble species of deer known as the Irish elk; magnificent horns of this animal have been found varying from ten to fourteen feet from tip to tip, whilst his height was not less than ten feet; various facts have been brought to light, making it almost certain that this animal, at least, finally became extinct through human agency.

We now come to the most remarkable of all the phenomena connected with the history of life on the earth. I mean the appearance of man. Few are ignorant of the discussions which have taken place on this point, and of the wide differences of opinion that still exist in reference to it. On the one hand, there are geologists who believe that man existed in the age that preceded the first great invasion of Europe by the ice-sheet. Others who reject this conclusion admit that he must have dwelt in Europe in the Inter-glacial age, whilst a third school of *savants* deem the evidence of even this degree of antiquity unsatisfactory, but suppose that he came hither after the final disappearance of the ice-sheet. But there are few, even of the latter class of geologists, who deny that man's antiquity as a dweller on the earth was very great; few who do not admit that he saw the Mammoth and the Reindeer feeding on the plains of southern France, and hence that he dwelt as a hunter amongst the many extinct Mammals whose names I have brought before you.

But before I deal with some of the evidence upon which we must base our conclusions respecting man's age, I must direct your attention to the history of one Tertiary and Post-tertiary group of animals which have assumed the highest interest in in consequence of the speculations of Professor Huxley in reference to it.

You all know that each foot of the horse has only one toe, which bears its nail or hoof. But every farrier is aware that on each side of the "cannon" bone there are two "splint" bones, and which are undoubtedly the degraded remnants of the second and fourth toes of the ordinary five-toed Mammalian foot. The two outermost toes, viz.: the first and the fifth, are altogether wanting, and in the case of the second and fourth the "metacarpals" and "metatarsals" as they are called—that is the bones which form the palm of the hand and the arch of the foot—are present in the shape of the two "splint" bones to which I have referred. Unlike the third toe, these two lateral splint bones have no digits, *i.e.*, proper toes or fingers, at their free ends. But Professor Huxley long ago called attention to the fact that in Post-pliocene times, when our modern horse had no existence, there lived a species of horse the "Hippotherium" in which the two splint bones *were* terminated by digits, but which were too short to reach the ground and take any part in bearing the weight of the animal. Going still further back into the Tertiary age, Huxley pointed out

the remains of another animal, the Anchitherium, which resembled the horse in many of its features, but in which the subsidiary second and fourth toes, though still smaller than the principal central one, were yet capable of reaching the ground. Professor Huxley came to the conclusion that the Anchitherium had first developed into the Hipparion and the Hipparion into the horse, and that this history gave a very powerful support to the doctrine of evolution. He asks, Which is the more probable conclusion at which we can arrive: that Europe once sustained herds of Anchitheria, which were swept away, to be replaced, through some miraculous agency, with similar herds of Hipparions, whilst these in like manner were supplanted by herds of horses of the modern type; or that, by a process of evolution, each of these successive types has been developed out of the pre-existing one? Huxley unhesitatingly accepts the latter alternative, and argues that if this is the true history of the horse, something similar to it must have been equally the history of all other animals.

Two questions arise out of this hypothesis: first, is this a correct account of the genealogy of the horse, and, if so, does it follow that all other animals must have had a similar genealogy. In endeavouring to trace out the ancestry of beings whose pedigrees have not been preserved, but have to be ascertained by means of circumstantial evidence, we have but one kind of trustworthy evidence. If all the examples of Anchitherium exhibit peculiarities of a distinctive kind which separate them *by a definite line of demarcation* from the Hipparions, and if the latter in turn are equally distinct from the modern horse, we have no evidence that the three distinct gradations in the development of the foot were the result of a succession of minute and impalpable changes *in which one type shaded off into another.* Such gradations are met with in the organic kingdom in innumerable instances. But if, on the other hand, a long and linear series of specimens of these animals can be put before us exhibiting, not interrupted gradations, but such a gradual transition from the Anchitherium to the horse, as renders it impossible to discover a break in the long line, then Professor Huxley's conclusion that the Anchitherium was the ancestor of the Hipparion and the Hipparion of the horse, becomes inevitable, and we must accept it whatever other conclusions may be rendered necessary by our doing so. Until recently the evidence that there had been such a transmutation was not satisfactory

to me. But in a recent lecture Professor Huxley has brought forward some additional evidence derived from Professor Marsh's discoveries in the western states of North America. Beyond all question some of the gaps which have hitherto separated the three animals I have named, are filled up by these discoveries; but I want yet more evidence before I can arrive at the conclusion that the doctrine of evolution is proved by these facts beyond the possibility of question. It appears to me that before I can unhesitatingly give to the testimony of these fossil horses the full value which I am asked to do, I must know more about them than is at present possible. It will not be enough that the limbs and teeth of these creatures indicate transmutation, but such transmutation must be evidenced by every part of the animal. This demand is especially applicable to the stages which intervene between the Hipparion and the horse. If the latter was evolved out of the former during long periods of time, it must have been so evolved *as a whole;* not merely showing the gradual change progressing in some organs, but in every portion of its structure; myriads of individuals must have existed to effect this gradual shading of the one into the other in every part of its body. It is true that in the Pliohippus of Professor Marsh, the two lateral metacarpals had no digits, but even between this form and the abortive splint bone of the horse, there is yet a wide gap. Further researches may fill up this and other similar gaps. The facts now known undoubtedly increase the probability that the doctrine of evolution alone can explain the existence of this series of horse-like animals, but the recognition of this *probability* is a very different thing from the admission of absolute certainty, which is practically demanded of us.

But even admitting all that Professor Huxley requires us to do, so far as the genealogy of the horse is concerned, does it follow that we must at once recognize in evolution the process to which all other forms of organic life are due? To this question I can only give a negative answer. I have already expressed my conviction of the applicability of the doctrine to the explanation of many of the variations of organic life, and I think it impossible to exaggerate its value as a working hypothesis; but beyond this I am, as yet, unable to go and for this reason: assuming Professor Huxley's hypothetical genealogy of the horse to be historically true, it only demonstrates what we already believed to be a fact, viz., that

changes in the surroundings of living organisms were capable of producing corresponding changes in those organisms *within certain limits.* In the present case we have only one part of the problem solved by nature's experiment. We have only the degradation, from disuse, of certain pre-existing organs—a process which throws no light whatever upon the opposite class of facts, in which entire organs make their appearance which had no previous existence. Animals already so closely allied to each other as to represent collectively the equine type, *began* with five toes, four of which successively disappear so far as only to be represented by the imperfect splint bones of the living horse, but we do not learn from these facts how animals originally became possessed of toes of any kind. Such information may be obtained from other sources or it may not—but the history of the horse certainly does *not* furnish us with it.

After this preliminary inquiry we may now proceed to ascertain what light has been thrown upon the corresponding history of man.

As is well known, numerous ancient relics have been found in various places, intimately associated with the remains of extinct animals, which no rational being can refuse to recognise as works of art fashioned by human hands. Rude works they are in many cases—but yet such as no unintelligent forces could have produced. The bone needle with its perforated eye, found by Mr. Pengelly in Kent's cavern, and the magnificent flint weapons which have been met with in so many localities, are illustrations of what I mean. The human origin of these objects being established, the all important point remaining to be proved is their age. Did the extinct animals, with whose bones these works of art are found associated, live into comparatively late ages, or did man exist in the remote period when Britain was a part of the European continent, and when the western extension of that continent stretched far out into the Atlantic?

There has been found one special set of memorials of a yet more interesting kind. I have already told you that as one of the consequences of the glacialisation of the northern hemisphere the Reindeer at one time abounded in southern France, where its remains now occur. Remarkable outlined sketches of these and other animals have been found in the same district, graven on pieces of their horns, on ivory, and on fragments of slate. In Sir John Lubbock's work

on the *Origin of Civilisation and the Primitive Condition of Man*; a book within the reach of all my hearers, you will see represented (p. 21) a group of Reindeer fighting, which was found in the south of France, and which could only have been delineated by some one familiar with these animals. In the same work is a still more remarkable outline scratched rudely on a piece of a Mammoth's tusk, and found in the Cave of La Madeleine in the Dordogne. From the sketch of the Mammoth given on page 90 it will be seen that the tusks of that animal curve upwards and inwards in a way that differs very widely from those of all living elephants; further, we know, from specimens found in Northern Siberia, that, unlike any of the living elephants, the anterior part of the Mammoth's body was hung with masses of long hair. Both these remarkable features reappear in the Dordogne sculpture. It seems to me extremely improbable that the ancient artist, even had he seen an African elephant —itself a very improbable supposition—would have so far diverged from his model as to reproduce exactly the two characters which distinguished the extinct Mammoth from its living representatives. The reproduction of one of these features would have been a remarkable coincidence; but that the two should be conjoined only appears explicable on the supposition that the artist had lived side by side with the extinct creature whose outlines he so accurately transferred to a fragment of one of its own tusks. The Esquimaux of the present day depict the animals living around them upon fragments of their own skeletons, and it appears to me that the men of the Post-glacial period, at which period we know that the Reindeer and the Mammoth flourished in southern Europe, only did the same. It is very improbable that a savage who had never seen a Mammoth could have elaborated it from his inner consciousness; he could merely have copied, as the Esquimaux do, such creatures as he was familiar with. I think we cannot avoid coming to the conclusion that, whatever may have been the age at which the sculptor of that animal lived, he was familiar with it; he used its ivory as one of the materials upon which to exercise his art; and we are consequently driven to the conclusion, that, however old or young man may be, he lived upon the earth at the time of these extinct animals. We next ask, in what shape does he personally present himself to us. We are told by the evolutionists that he was originally a monkey. This is not necessarily an

improbable fact; we must not scout the idea merely because we are apt to smile at it; we must look at the evidence upon which the hypothesis rests. There is no doubt whatever that man is constructed upon the same type as the monkey, and that when you put their skeletons side by side, though there are certain points of difference, there are greater and stronger points of resemblance. Consequently, *à priori*, assuming that the doctrine of evolution is true, it would be extremely probable that man had developed out of one of the larger and more man-like types of ape. If we merely study man's skeleton as a whole, I can obtain from it no evidence that necessarily upsets the conclusions of the evolutionists; but when we come to study certain special features, I think I see very grave difficulties. In the first place, when we examine the brain-pan of the monkey and compare it with that of man, I need scarcely say how large is the difference between the magnitude of the human brain and that of the highest type of monkey that we are familiar with. Of course it is very difficult to decide how much these differences are worth. We sometimes find a man with a little brain made of superior material, who, mentally, surpasses another man with a bigger brain made of baser material. But let us see to what this comparison of brain-power brings us. The largest Gorilla has a brain of about thirty-four and a half inches of cubic capacity; but this magnitude is exceptional; generally speaking, the brain of the Gorilla has from thirty to thirty-two inches of cubic capacity. The brain of the highest form of intellectual man has about 114 inches of cubic capacity. Between these two extremes there is an enormous difference. But the evolutionist properly says, "I have nothing to do with extremes; I have only to study the highest form of ape and the lowest form of man, to see if a link can be found uniting the two."

The smallest known adult human brain, respecting the accuracy of the measurements of which there exists no room for doubt, is one described by Professor Marshall of London. It is that of a Hottentot woman; we do not know her age or whether or not she was an idiot. When we find the brains of Englishmen and Europeans with a less cubic capacity than about sixty inches, we are told by Dr. Davis, one of our highest authorities on this subject, that they are invariably those of idiots; but it does not follow that this brain capacity would necessarily indicate idiocy in savages. The brain of the Hottentot woman measured sixty-two and a half cubic inches.

The evolutionists argue that since there is such a diversity in the brain of humanity, varying from 114 cubic inches to sixty-two, there is no reason why we should not go down to thirty inches and reach the level of the Gorilla. I contend that this is not a philosophical argument, and I will tell you why. Suppose you try to stretch a cord already three feet long, you may easily add some inches to its length; but having done this you will find it far more difficult to stretch it another inch than you did to stretch it the first half-dozen. You have reached the limit of its elasticity, and, use what effort you may, any further strain only snaps it in two. Apply this to the human brain. It is true there is an elasticity in the development of this organ that admits of its ranging between 62 and 114 inches, but because you have got so low as 62 inches it does not follow that it could be reduced in size to the extent of 28 inches more. I think this statement is sustained by archæological evidence. The two oldest human crania that have yet been found are those known as the Engis and Neanderthal skulls. Of these the former was unquestionably the more ancient. Yet Professor Huxley admits that it has probably a cubic capacity of 75 inches, and might have belonged either to a negro or to a philosopher. The Neanderthal specimen is much more imperfect, hence its exact capacity is not easily calculated; but it was probably much inferior to the Engis one, though its owner lived at a later period of time than was the case with the Engis savage. We thus see that the facts exhibited by the oldest known skull carries us far away from the Gorilla, and leave us solely dependent upon possibilities in attempting to build up our hypotheses. I am brought to the conclusion, that, so far as the skull is concerned, there is a wide gulf yet to be bridged over, deeper than the uncompromising advocates of evolution appear to recognise. But it is not to brain measurements, nor to any other merely structural peculiarities, that I am inclined to look for evidence bearing upon this problem—but to the psychological peculiarities which separate man from the most exalted of the lower creatures. The caves of the Dordogne reveal primæval man to us as an artist—rude, it is true, yet using his flint stones as graving tools, and sculpturing, with these imperfect implements, life-like representations of the creatures amongst which he lived. Now what have we in any Gorilla that prepares us for these manifestations of artistic talent? Literally nothing: yet this is only one of the in-

numerable mental and moral potentialities which separate man from the brute. It appears to me unphilosophical to say that these powers have been produced by the influence of man's surroundings acting upon his organisation. I would urge that all that those surroundings have effected has been, not to create, but to call into activity, powers that were already latent in man's nature. When we talk about what civilisation has gradually accomplished, we must remember that civilisation has proceeded from the exercise of qualities residing *within* man himself, and not from physical influences operating from *without*—hence civilisation, so far from being a product of the "surroundings" of Mr. Spencer, is merely a proof of the existence in man of latent potentialities, which no surroundings could create, however much they might aid in stimulating them into activity. As it is, there is no race of men so degraded that they cannot be taught in the course of a very few generations to display mental qualities to which the mere animal, however long he may have dwelt within the influence of civilised man, can lay no claim. Man can not only look backwards by an effort of memory, but anticipate the possible joys and sorrows of the future, which no animal can do. He can entertain abstract conceptions of good and evil, of beauty and its opposites, of right and wrong. He can work out the most intricate intellectual problems by processes even more intricate than the problems to be solved; and finally, when we regard man in the loftiest of his relations, we find him in possession of a sense of responsibility, not only to his fellowmen, but to the Supreme Ruler of the Universe; he has almost always some abstract conception, however vague, of a Being whom his eye hath not seen, but to whom his instincts tell him that he must one day render an account of his doings whilst on earth, and from whom he expects to receive a future life; a hope in which the most developed of brutes has no part.

MANCHESTER SCIENCE LECTURES FOR THE PEOPLE.

EIGHTH SERIES. WINTER SESSION, 1876.

WHY THE EARTH'S CHEMISTRY IS AS IT IS.

BY J. NORMAN LOCKYER, ESQ., F.R.S.

LECTURE I.

In the three preceding lectures of this series, the chemical constitution of the Earth has been brought before you, and my part in the course, as I understand it, is to deal with the bodies, so far as we know them, which people space; in order that the earth's true place in nature, so far as its chemical and physical constitution is concerned, may be ascertained, and the reasons for that constitution inquired into.

For this purpose it is necessary that I should enter at some length into the constitution of those masses of matter which lie beyond the earth on which we dwell, and even beyond the system, and, it may be, the universe, of which we form a part. And you will naturally—some of you at least—ask, How is it possible that such knowledge as this has been attained? Prof. Roscoe, when he wished to tell you about the chemical composition of the earth's crust, was enabled to bring before you specimens of its different constituents, and could tell you how these specimens had been handled and weighed and experimented upon in different ways in his laboratory; but when we have to deal with the chemical constitution of bodies so

many millions of miles removed from us that we know as a matter of fact that the light which now enables us to see them must have left them hundreds of years ago, it is perfectly clear that such methods as those indicated by Dr. Roscoe are entirely powerless. In fact some other process is needed, with one exception. There are certain celestial messengers come to us from time to time which we can touch and which we can handle—I mean Meteorites, which appear to us as falling stars or aërolites; bright, beautiful objects, like those rockets which are going up to-night, and which, fortunately for science, last long enough to come down to the solid crust of the earth, where they cool and where we may subsequently examine them, as Dr. Roscoe has already told you. But with this exception, it is clear to you that ordinary chemical processes are entirely out of the question.

The progress of physical science has been in this wise:—As man has grown older the earth on which we dwell has dwindled down. It began as the centre of the universe; it has ended as a small mass of matter revolving round what probably is a small star—I mean the sun. But although the progress of science has been thus in a way to degrade the earth, I am sure you will think with me that man's intellect has been a distinct gainer by the process; for it is not too much to say that as the earth's place in nature has dwindled down, so has man's mental horizon been extended. That is very well shown by two fundamental considerations which I must bring before you in the first instance. In the year 1610, or thereabouts, that is to say, about two centuries and a half ago, thanks to the labours of men in Holland and in Italy, but chiefly to the genius of the immortal Galileo, the telescope was invented, and we got an untold addition to our mental wealth. The skies were peopled by means of the telescope, and the earth, which up to that time had been supposed the centre of everything, was put in its right place; bodies were observed shining millions and millions of miles away—bodies which up to that time had bathed the earth with light without any response from the human eye; and what was the result? Philosophers were enabled to class all the shining orbs of heaven into two great divisions—those bodies, namely, which shone like the sun with a light of their own, and those which shone by borrowed light. The bodies which were found to shine by borrowed light and not by any light of their own were bodies which eventually were classed together

and termed the solar system—a family of planets which go round the sun, each in its proper path, each in its proper time; which are lighted up by the sun; which are warmed by the sun, and to the inhabitants of which the sun is the fountain of every kind of energy. We have from this classification the first great grouping of celestial bodies into those which shine by their own light, which, with the exception of the sun, are outside the solar system; and into those which shine by reflected light, which classification included all the bodies of the solar system except the sun. Now I will throw on the screen a diagram of the solar system, in order that you may exactly see which these bodies are, that reflect light, and in this case the light of the sun. I am very anxious indeed that you should understand the importance of this first classification, because the next one which I shall have to bring before you will go very much further into detail. We have, as representing the bodies of the solar system, first of all in the centre the Sun, which shines by its own light; and next, in the order of distance from it, Mercury, Venus, the Earth, Mars, a group of small planets called the Asteroids; then after them, Jupiter, Saturn, Uranus, and Neptune; Neptune being the last member of the solar family, so far as our knowledge at present goes.

When I call your attention to the next classification, I shall no longer have to refer to the illustrious Florentine, but to your own townsman, Professor Balfour Stewart, and to Professor Stokes. Their labours have given us another and more searching grouping, so to speak, by which we can go into much greater detail. This grouping is no longer based on the teachings of the telescope, but on the teachings of the spectroscope; and here, if you will allow me, I will state as briefly as may be the nature of this teaching, as you will find it of extreme importance, as we go along, to understand the terminology which I shall have to use. The important results to which we have arrived—thanks to the work of Stewart, Stokes, and others, and to the introduction of the spectroscope—can be shortly stated.

So long as Dr. Roscoe was telling you about taking a specimen of iron and analysing it, and taking a specimen of calcium and weighing it, and so on, it might not have been perfectly obvious to all of you that before you could recognise the existence of that calcium, and before you could see the beam of the scale go up or down, according to the precise weight of

it, a certain connection had been established between that calcium, let us say, and yourself—your consciousness. But when I shall have to tell of the chemical constitution of bodies thousands of millions of miles away, the necessity for some connection between our eyes—our consciousness—and those distant objects, will force itself upon us; and it is important therefore at the threshold that we should refer to it. These distant bodies are visible to us by means of their unrest; if all the bodies in space were absolutely tranquil we should never see them; but the normal condition of everything in nature is a state of most beautiful and exquisite unrest. Scientific men call this a state of vibration; but we need not quarrel about terms. Everything in nature, far or near, is in this state of unrest, and if it were not so there would be for us no external world. From every material substance, including these distant worlds, the vibrations of their smallest particles or of their largest masses come to us along a medium which scientific men call ether, not that they know all about it, but because it is necessary, in order that their work may go on at all, that they should assume that there is a something infinitely finer than matter, and not at all like the attenuated matter which pervades all space. This ether forms the highway along which the vibrations due to the state of unrest of matter travel to our eye, and afterwards to our brain, thus begetting in our consciousness the impression of the material world.

Here, then, we have a vibration of the most distant mass of matter in the universe communicated to our optic nerves by means of this ether. How comes it that any chemical knowledge can be acquired concerning these bodies? In this way. The spectroscope tells us that when we break a mass of matter down to its finest particles, or, as some people prefer to call them, ultimate molecules, the vibrations of these ultimate parts of each different kind of matter are absolutely distinct; so that if I get the ultimate particle, say of calcium, and observe its vibrations by scientific means—what those scientific means are I shall show you by and by—we find that the kind of unrest of one substance—of the calcium, for instance—is different from the kind of unrest or mode of vibration—which is the same thing—of another substance, let us say sodium. Mark well that I say when we have brought these substances down to their ultimate or to almost their ultimate finenesses, because until we have done so the

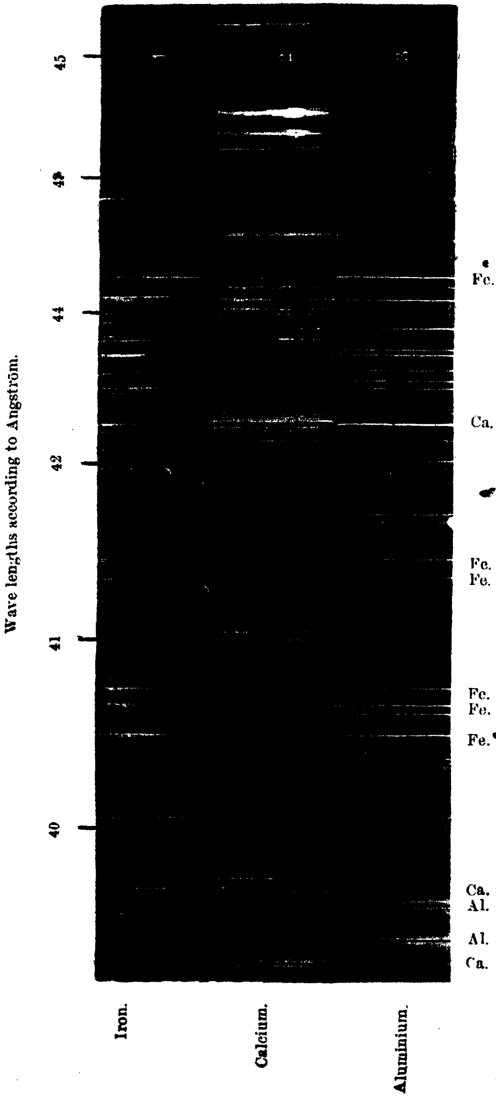


Fig. 1.—Comparison of the line spectra of Iron, Calcium, and Aluminium, with common impurities. Copy of a photograph by Lockyer, in which, by dividing the slit of the spectroscope into sections, and admitting light from the various light sources through them in succession, spectra of different elements are recorded on the same photographic plate.

vibrations of the larger molecular aggregations are absolutely powerless to tell us anything about their chemical nature, but they are full of teaching as to physical conditions.

Now we know that when we bring down a substance to its finest state and observe, by means of the prism, the vibrations it communicates to the ether, we find that using a slit in the spectroscope and making these vibrations paint different images of the slit, we get at once just as distinct a series of images of the slit for each substance as we would get a distinct sequence of notes if we were playing different tunes on a piano. I have here a photograph which has been produced by such vibrations. I hope first to show you on the screen what is called the line spectrum due to the smallest particles of calcium and aluminium; and if I am successful you will perfectly understand the meaning of the term line spectrum. Here are the lines by which the metal calcium is recognised when the vibrations of its finest particles are observed by means of the spectroscope. The two central lines give you also the vibrations due to aluminium. If you look to the other part of the screen you will think perhaps that you are dealing with a different order of phenomena altogether, and in that you will be perfectly justified. In truth we have here on the same screen not only the line spectra of calcium and of aluminium, but what is termed the channelled space spectrum of carbon; that is to say, while the calcium and the aluminium have been driven down to their finest states of separation by dissociation, the carbon has not been driven down so low, and therefore we get a different kind of spectrum.

These vibrations having been rendered, I hope, intelligible by means of these drawings, this important consideration comes into play—that whenever any element finds itself in this state of fineness and therefore competent to give rise to these phenomena, it will give rise to them in different degrees according to certain conditions. The intensest form in which they may be brought before you is observed when we employ electricity. In a great many cases the vibrations may be rendered very intense by heat. The heat of a furnace or of gas will, for instance, in a great many cases, suffice to give us these phenomena; but to see them in all their magnificence, their most extreme cases, we want the highest possible temperatures, or better still, the most extreme electric energy. What we get is the vibration of these particles rendered visible

to our eye by the bright images of the slit or by their bright "lines."

But that is not the only means we have of studying these states of unrest. We can study them almost equally well if, instead of dealing with the radiation of light from the particles themselves, we interpose them between us and a light-source of more complicated molecular structure, and hotter or more violently excited than the particles themselves. From such a source the light would come to us absolutely complete, as it is coming to us now from that gas; that is to say, a perfectly complete gamut of waves of light, from extreme red to extreme violet. I say that when we deal with these particles between us and a light-source competent to give us a *continuous spectrum*, then we find that the functions of these molecules are still the same, but that their effect upon our retinas is different. They are not vibrating strongly enough to give us effectively light of their own, but they are eager to vibrate, and, being so, they are employed, so to speak, in absorbing the light which otherwise would come to our eyes. So that whether we observe the bright spectrum of calcium or any other metal, or the absorption spectrum, we get lines exactly in the same part of the chromatic gamut, with the difference that when we are dealing with radiation we get bright lines, and when dealing with absorption we get dark ones.

Now that being so, it will be perfectly clear to all of you that we have it in our power to enormously extend the inquiries started by Galileo. We need no longer be content with dividing the non-terrestrial bodies into those which shine by their own light and those which shine by reflected light, but we may make a classification of this kind. We have first of all those bodies which we can study by means of the radiation of their molecules, that is to say bodies in which the mere state of unrest, as I have ventured to call it, the mere giving out of light by the molecules of which these celestial masses consist, is the only thing in question. Then again, we have another class in which we deal not only with the radiation of the interior, but with the absorption of the molecules or particles by which each body is surrounded. Then we have, to come back to Galileo's classification somewhat, those bodies which we observe by means of light which they reflect to us. Then again there may be, and in fact there is, a class of bodies which, although they send their light to us by reflection, still make this light, so to speak, pay

a second toll on its passage, and it comes to us reflected and absorbed.

NEBULÆ AND COMETS.

When we examine into the various bodies which people the skies, we find that among those which can be studied by means of their radiation alone there are two of the very largest groups. I refer to nebulæ and comets. Let us first deal with the nebulæ. A very small telescope indeed is all that is requisite to see some of the most magnificent nebulæ in the heavens. I will throw on the screen Lord Rosse's drawing of the nebula of Orion; but before I do so I should like to show you how the spectroscopic addition to our knowledge has been secured. For this purpose I can show you a drawing of the eye end of the largest telescope in England at the present time, one belonging to a North-countryman, Mr. Newall, of Gateshead, and you will at once understand how the spectroscope has been used to aid the telescope to obtain these additions to our knowledge which I shall have to bring before you. Here is the eye-piece end of Mr. Newall's telescope, which, magnified in this way, is perhaps about life size, the object-glass being some twenty-five inches in diameter, and the focal length thirty or thirty-one feet. At the eye-piece end of the telescope we have attached to it at the focus the spectroscope, with a number of prisms depending upon the amount of light which each heavenly body which has to be investigated gives out. In this drawing I have shown the greatest number of prisms which are used when it is a question of observing the sun; but, as you will readily understand, if instead of observing the light of the sun concentrated by this enormous instrument, it is a question of observing the nebulæ and some of the fainter stars, then, as there is always a loss of light by making it traverse through any great thickness of glass, the number of prisms is much reduced; so that you may say broadly that we have the greatest possible number of prisms for observing the sun, and the smallest possible number of prisms, say one or two, for observing the spectra of the nebulæ and the spectra of the fixed stars —at all events of the fainter ones. I propose, in dealing both with the nebulæ and with comets, first to refer to the telescopic appearance of these heavenly bodies and then

afterwards draw attention to the spectroscopic results which have followed.

The question of the chemical and physical constitution of the nebulæ is one perhaps of the most interesting in the whole range of astronomical science, and it has occupied the attention of our most illustrious astronomers. Having now before you the *modus operandi,* I will throw the drawing of the nebula, which

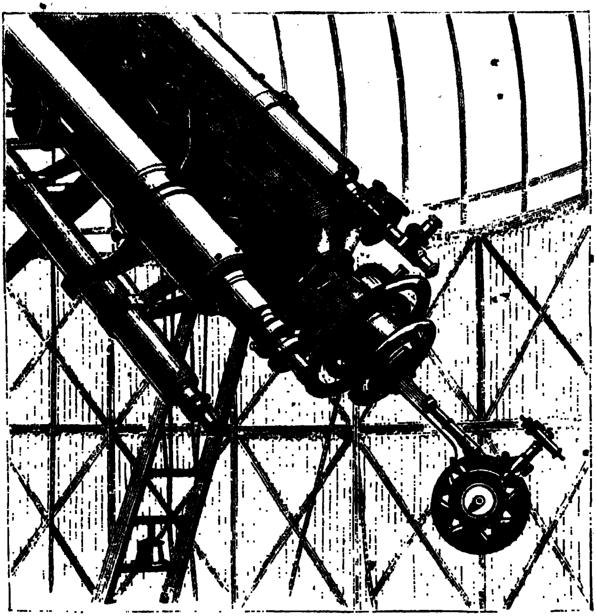


FIG. 2.—The eye-piece end of the Newall refractor (of 25 inches aperture) with spectroscope attached.

in these latitudes is most easily seen with the smallest instrument, and which, although it can be thus seen, is nevertheless one of the most magnificent objects in the whole heavens: I refer to the nebula of Orion. The first thing that strikes us about this nebula is its intense irregularity; there seems to be nothing celestial about it. Here and there we have great waves of light going along in diffuse courses from the central portion. Here

and there we have stars surrounded by a smaller nebulosity. Here again we have stars without any nebulosity at all; and look where we will, we see fleecy contortions and the most wondrous irregularity. Now it was not to be wondered at

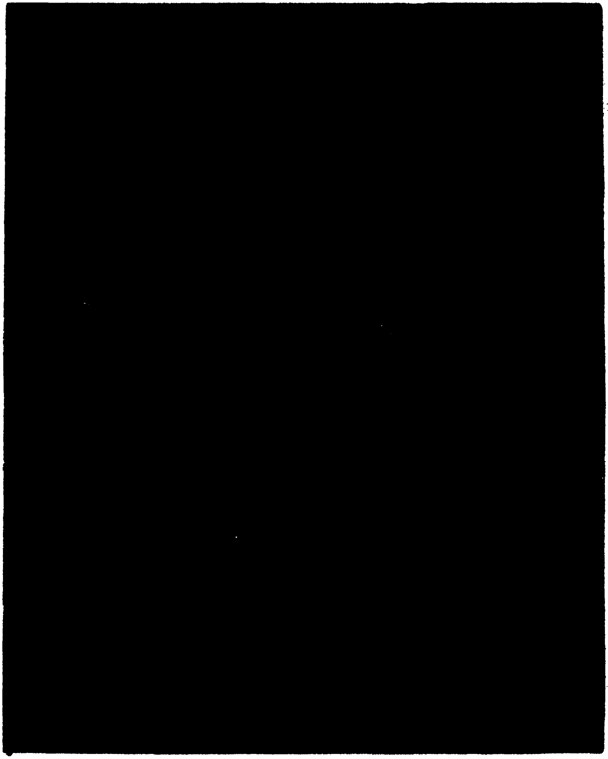


FIG. 3.—Copy of Lord Rosse's drawing of the Nebula of Orion.

that with the earliest telescopes the wildest guesses and the most profound thoughts were associated with these strange bodies. If we look at the works of Tycho Brahe and others, before the time of the astronomers of the last century, we find

them all occupied with an attempt at understanding the physics and the chemistry of these strange cosmical masses. Some were content to look upon them as fire-dust; others saw in them enormous star clusters so infinitely removed that each element of the nebulosity might represent a single star, the single star being so far away, however, that, like the Milky Way, which we know to be composed of stars, to the naked eye the individuality of the stars did not come out. In the last century however, when Sir William Herschel with his wonderful perseverance at last had succeeded in eclipsing all former optical instruments by his magnificent forty-feet instru-

FIG. 4.—Nebula in process of condensation.

ment at Slough, then indeed the scientific study of nebulæ may be said to have commenced, and in a few years he had made lists of thousands of nebulæ; and his son, Sir John Herschel, later went to the Cape and added thousands more. Nearer our own time the magnificent instrument of Lord Rosse, at Parsonstown, has added to our knowledge, so that now the list of nebulæ is very considerable indeed. You will ask, Has the wonder connected with these strange objects been reduced by extended observations? I think I shall be able easily to show you that it has not been so reduced. Here, so far as form goes, we get a complete absence of all form—

absolute irregularity. Allow me to call your attention to some other drawings of nebulæ made by Lord Rosse, in which the irregularity typified by the nebula of Orion has given place to something absolutely different. Here we have an approximation to form and regularity, although the regularity is of different kinds. We have spiral nebulæ, annular nebulæ, and, as I may term them, *Saturnine* nebulæ. Note well the fact that the moment we leave the extreme irregularity of the nebula of Orion we always have to do with a condensation of some kind or other; in some cases with something between concentric and spiral convolutions round the central condensation.

Here is another series of nebulæ observed in the first instance by Sir John Herschel, which will intensify the classification to which I have referred. We have again spirals

FIG. 5.—Saturnine Nebula.

and double spirals. Finally, I will show you one of the most magnificent spiral nebulæ in the heavens from the same set of drawings. You see that the central condensation is fed, as it were, by spirals in all directions, some of them having condensations on the different branches. Now, Humboldt was not in possession of all these observations which I have been able to bring before you to-night, but he sums up in the first volume of his *Cosmos* these various forms of nebulæ in a very effective way. This summary will well repay perusal.

Now what are the modern ideas of the constitution of these strange bodies? I have already referred to the ideas of Tycho Brahe, Cassini, and the earlier observers. The work of the two Herschels left it as highly probable that these nebulæ

were really masses of cosmic dust, so to speak, or some kind of gaseous or vaporous material, which took these strange forms because there was nothing solid about them. But when Lord Rosse, with improved optical means, investigated some of the nebulæ which had been called irresolvable—a name given because no telescope up to that time was able to break them up into separate stars—he found that his telescope did break them up into distinct points of light, and then for a time in the pre-spectroscopic age, as one may call it, opinion swung round, and held that these nebulæ simply appeared as nebulæ not because they did not consist of stars, but because they were so far away that we could not see the separate stars of which they were composed. But not many years ago Dr. Huggins—to whom belongs the credit of having first turned the spectroscope

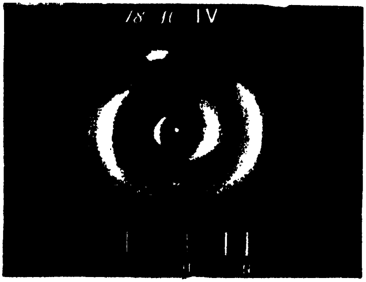


FIG. 6.—Nebula with rings.

on to the nebulæ—was enabled to show beyond all shadow of a doubt, that we had in the nebulæ something absolutely and completely distinct from stars. Dr. Huggins found, on turning his spectroscope upon several of these bodies, that the spectrum which he got from all of them was most characteristic. It was a bright line spectrum, and there was one line which was common to all of them. In the lower part of the diagram the bright lines visible in the spectra of the different nebulæ are shown; and below, for purposes of reference, Dr. Huggins has shown the positions of various bright lines in the spectra given by other substances. There, for instance, in the blue green, is the bright line due to hydrogen; there is another line in the green due to magnesium; a line in the yellow due to sodium; and so on; and with these points of reference we

can easily determine the place in the spectrum of the three bright lines which Dr. Huggins found to be visible in the spectra of almost all the nebulæ examined; the differences between nebulæ and nebulæ, as I understand them, being indicated by the relative intensity of the lines, and the amount of continuous spectrum associated with them.

Having this enormous addition to our knowledge—the fact, namely, that the light given out by nebulæ is perfectly distinct from the light given out by stars—men of science were able to study the nature of nebulæ from a perfectly new standpoint.

One of the lines of the nebulæ is really coincident with a line of hydrogen, or, in other words, we have to deal with hydrogen gas when we are dealing with nebulæ. This has

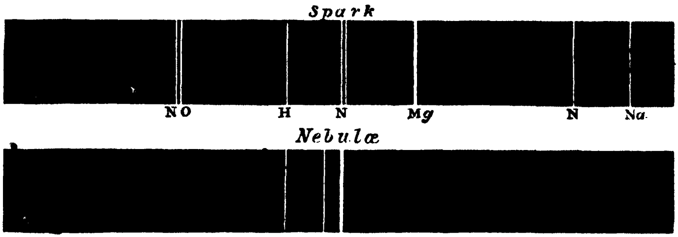


FIG. 7.—Spectrum of the Nebulæ (Huggins) compared with the bright lines of certain elements.

been a most interesting and important point of departure. Dr. Huggins is of opinion that the nebulæ consist of masses of hydrogen gas; that there is nothing solid in the nebulæ, that it is a mere question of incandescent hydrogen, associated with something else, the chemical constitution of which has not yet been thoroughly established, because Dr. Huggins, with all his diligence, has not been able from his examination of the other chemical elements known, to get lines corresponding to those other two which we saw on the screen. But that is not the only view held as to the constitution of nebulæ. Sir William Thomson and Professor Tait consider it extremely probable that the nebulæ, instead of being masses of gas, may consist of clouds of stones. Now this at first seems so entirely at variance with the spectroscopic result that it is

not to be wondered at that the idea was at first considered to be somewhat *bizarre* and strange; but if one comes to think the matter out, one finds that there is a great deal of method in this strangeness, because Sir William Thomson and Professor Tait point out that if you had a cloud of stones, each one of which was in motion, and therefore liable to come into collision with some other stone now and then, you would get heat quite sufficient to render any circumambient gas incandescent; so that the phenomena of the spectroscope could be explained equally well on the assumption of a cloud of stones, providing always that you could at the same time show reasonable cause why these clouds of stones were "banging about" in an atmosphere of hydrogen. But nebulæ are not the only things in the universe which these distinguished Scotch professors imagine to be composed of clouds of stones. I think it is better therefore that I should postpone the further discussion of this point until we have become acquainted with the second class of bodies, which we study by means of their radiation—I refer to comets.

COMETS.

Now when we pass from a nebula to a comet, it is clear that we come to a body of a perfectly different order in the celestial economy. Comets are distinguished from the nebulæ in many ways. The nebulæ, as a rule, are very far removed from us, so far that we have not the least idea of the distance of any one of them—we know that they are not within certain limits, and that they are also at rest apparently among the stars, while the comets are erratic bodies, which are now in our system, and now out of it; now close to us, and now infinitely removed in the depths of space.

Further, we know that the comets are not at all like the planets any more than they are like the nebulæ, because while our planets as a rule, excepting the smaller members or minor planets of the system, keep to one plane round the sun, called the plane of the ecliptic, which we may liken to a racecourse, round which all these planets pursue their revolutions—the comets do not keep to this plane, for they are as likely to dash into our system from above or below as they are to come into our system on the same plane as the planets. But more than this, while all the planets of our system are bound together by a motion which is always in the same direction

round the sun, when a comet comes into our system it is just as likely to go round the sun in an opposite direction. So that in the comets we have a complete differentiation between comet and nebula on the one hand, and comet and planet on the other.

I have here two or three general views which will give you a rough idea of the telescopic appearances of these strange visitors to our system. The peculiarity connected with comets generally is a double one—they have a bright head, and they have one or two or several appendages, called tails, which go from the head in a certain direction. There we have a comet with two tails—here with three; but these are not different comets; that is the comet which appeared in 1858, as seen at two different times. These views will give you a general idea of the appearance of comets, and of the way in which they travel among the stars. The physical interest of comets, which I shall have to call your attention to, is more intimately connected with the heads than with the tails; and I shall therefore hope to show you two or three more drawings, in which the heads of these comets will be in question. The characteristics of the heads are chiefly these—that in some cases we have to deal with what are called jets. The brightest point is called the nucleus of the comet, and the jets are so called because they seem to shoot out from the nucleus very much as the sparks shoot out of a squib.

Drawings of a comet, as seen at different times, show how these jets vary in appearance and direction. Instead of jets, some comets present phenomena of a very different character, called envelopes, which are thrown off concentrically from the nucleus. These envelopes are indicated in this drawing of a comet, made by Father Secchi in Rome. These then are the two physical peculiarities about the heads of comets; and you will see at once that we have something perfectly distinct from the nebulæ and the planets, and that one class of comets is at first sight different from another. The envelopes have been observed to rise from the nucleus with perfect and exquisite regularity in exactly the same way that the jets swing backwards and forwards. So much then for a very rough telescopic idea of the phenomena of comets.

What then says the spectroscope? I will now show you the diagram which I showed you before, in order to call your attention to another part of it. Formerly I called your attention to the spectrum of the nebulæ. I will now call your attention

to the spectrum of comets, and I am glad to have both the diagrams on the screen at the same time, because you will see that the spectroscopic difference is just as great as the telescopic difference. Now let me ask you to recall one of the first photographs I showed you—that of the carbon spectrum—and my definition of the channelled-space spectrum. You will at once recognise, I am sure, that here we have exactly that same kind of channelled-space spectrum that we had before. Side by side with this channelled-space spectrum,

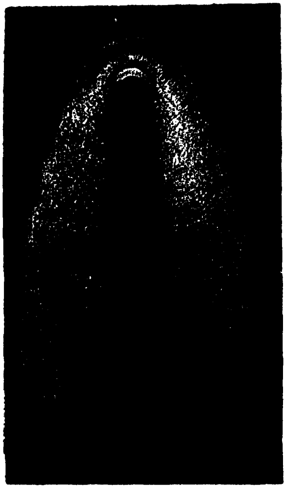


FIG. 8.—Concentric envelopes of Donati's Comet.

which is the spectrum of carbon, we have the spectrum of the comet, and you will see that the family likeness is very considerable, although it is true that the brightest portions of the spectrum of the comet are not absolutely coincident with the brightest portions of the spectrum of carbon which Mr. Huggins has drawn in the upper part of the diagram. What, then, is the meaning of this spectroscopic result? It is stated that if the spectroscope tells us anything, it tells us that we have to deal with carbon, or with hydro-carbon, as certainly in the case of comets, as we had to deal with hydrogen in the case of nebulæ. Here then we have a definite result with regard

to the brighter portions of the comets, that is to say, the nucleus, the envelopes, and the jets; but how about the tail? The same instrument, and the polariscope, when brought to bear on these longer appendages of comets, tell us that there we have perhaps no longer to deal with hydro-carbon, certainly not with hydrocarbon in a state of considerable unrest, for we do not get the characteristic spectrum of hydro-carbon; we get apparently from the tails merely sun-light reflected. Are we then to say that comets are built up of hydro-carbon? No. Here again Professors Thomson and Tait come in and insist strangely enough that comets as well as nebulæ are masses of stones; that, in short, a comet is a bit of a nebula,

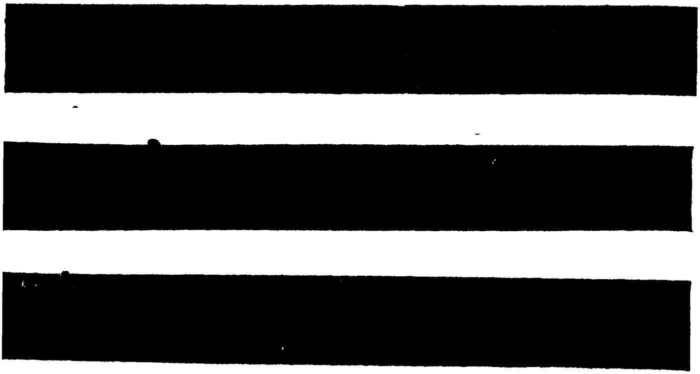


FIG. 9.—Cometary spectrum (Huggins).

differing from a nebula in this, that it is in violent motion as a whole, while the nebula is apparently at rest as a whole. You will find in *Good Words* of a few months ago an important article by Professor Tait, in which he goes into this question at very great length. He shows that if we have in the head of a comet a mass of stones, like a swarm of bees, banging about, and, at the same time, moving in an orbit around the sun, or it may be in its long path from the centre of our system to the centre of another system, and the stones colliding, you will get heat, and some gas will be evolved; some members of the mass will be quickened, while other constituents of the mass will be retarded in their motion, and

that in this way you have a probably sufficient explanation of the various forms which the telescope has revealed to us. And then finally he goes on to show that the result of these collisions would be such a smashing up of the constituents of the swarm that much finely-attenuated material would be left behind, sufficient to reflect sunlight, and to give rise to the phenomena of the tail.

Now, curiously enough, while these ideas have been evolving themselves, a distinguished Italian astronomer, Schiaparelli, had also arrived at the conclusion that comets were closely connected with swarms of meteors; and he arrived at this conclusion by an examination of the paths of the meteors and the paths of certain comets. Astronomers now know exactly when to look out for what they call a meteor-swarm, or a mass of shooting-stars. They know, for instance, that on the night of the 20th of April they will most probably see shooting-stars coming from the constellation Lyra, and these shooting-stars they call the Lyriad shower. They know also that on the 10th and 11th of August they will see other shooting-stars, this time coming from the constellation Perseus. These also they call the Perseids. On Nov. 13 and 14 the Leonids may be expected, that is to say, that then is the time to look out for shooting stars which come from the constellation Leo. Now if astronomers can tell you that on a certain night—that is to say, when the earth is in a certain position in its orbit shooting-stars will appear to come from a certain part of the heavens, namely, some particular constellation, it is because they have become acquainted with the path of those meteors round the sun. They have, in fact been able to get a very concrete idea of the orbits of those meteors, in the same way that we have a concrete idea of the orbit of the earth round the sun. They can tell exactly where and when they cut the plane of the ecliptic, and other things which I need not bring before you in detail. After comets have appeared two or three times, astronomers can also form an equally definite idea of their orbit round the sun. Now, what Schiaparelli did was this—he compared the orbits of these meteoric swarms with those of some of the comets, and he found some of them identical. For instance, in the case of the shower of April 20th in each year he found that there was a comet observed carefully in 1861 with absolutely the same path; for those shooting-stars which radiate from the constellation Perseus on 10th August he found that a comet observed in 1862 had exactly

the same path; for the Leonids, which appear on 13th and 14th November, he found that a comet, observed and calculated out accurately in the year 1866, had exactly the same path. And

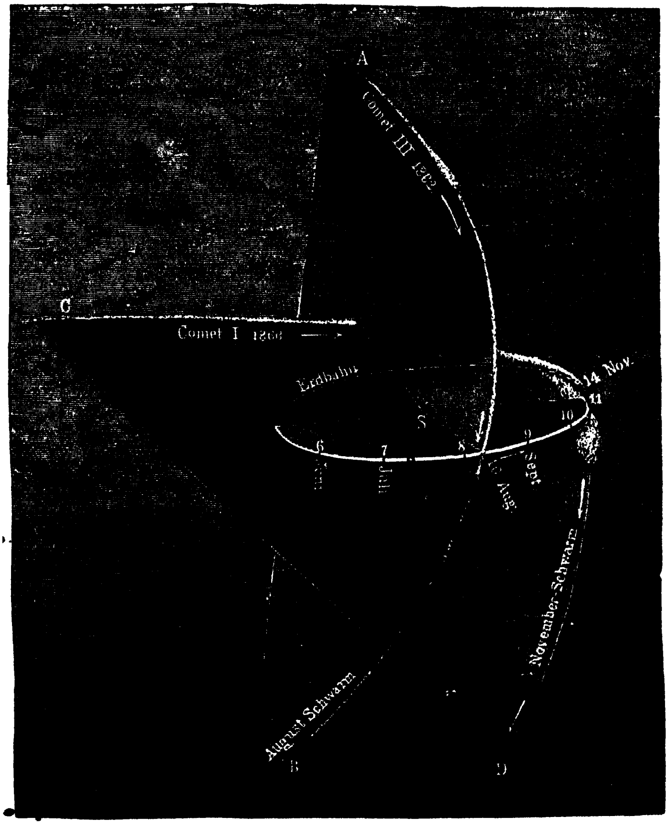


FIG. 10.—Diagram showing the paths of Comet I., 1868, and III., 1862, and their accompanying meteor swarms, and the points at which they cut the earth's path.

then with regard to the other principal group observed on the 27th and 28th November, he found that the falling stars seen in the constellation Andromeda on those nights had

exactly the orbit as a very well-calculated and most remarkable comet named after Biela the astronomer. Now, of course this suggestion of Schiaparelli gave an enormously increased interest to the investigation both of comets and meteors, and when the question was thoroughly gone into it was impossible to avoid the conclusion that when we have a shower of falling-stars we practically are going through part of a comet; and that when we see a comet in the sky we actually are seeing the behaviour of a swarm of meteors at a distance.

I hope to commence my next lecture by referring to some other considerations with regard to these meteorites, and then to call your attention to some experiments which suggest that the connection between meteors or falling-stars, comets and nebulæ, is of the very closest description.

WHY THE EARTH'S CHEMISTRY IS AS IT IS.

LECTURE II.

IN the latter part of the last Lecture I referred to the chemical constitution of comets, so far as the spectroscope enables us to determine this constitution; and I endeavoured to point out to you what the telescope had revealed to us with reference to their physical constitution. I also again dwelt on one of the great triumphs of modern astronomy—namely, the discovery by Schiaparelli of the intimate connection between falling stars and comets.

METEORITES.

Now, from the falling star to the meteorite is a step so small that nothing need be said about it by me to-night. The difference between a falling star and a meteorite is simply this—that a falling star is a small mass of matter which is entirely burnt up in its passage through the higher regions of our air, whereas the meteorite is a falling star big enough to give us some residuum after the energetic action of heat has worked its will upon it in passing through the atmosphere. Observations of the rapidity with which falling stars and meteorites traverse our atmosphere have shown beyond a doubt that a meteorite could travel, say from Manchester to London, in as many seconds as an express train takes hours. You may imagine, therefore, that owing to this very rapid motion through a medium—and a medium constantly increasing in density—such as our air, that a considerable resistance is offered to the passage of the meteorite. This arrested motion in process of time becomes developed into what we call heat, and as a result in all cases we get

luminous effects, with this difference, that, whereas in the case of the falling star, the luminous effect is the only thing we get, in other cases we get in addition to it the actual descent of what we may term a celestial messenger from the depths of space. Of course, having these meteorites—these larger masses—falling to the earth, so that we can handle them, a great deal has been learned about their chemical and physical constitution, as Dr. Roscoe has already told you. I need not dwell at any great length upon this, after what Dr. Roscoe has said; but I may state that, generically, these celestial messengers may be divided into four groups. We have those which are almost entirely metallic. We have those which are almost entirely stony. We have those in which the metallic and the stony constituents are mixed in various proportions; and in a fourth, or last class, in addition to the materials to which I have already referred, there are to be found various combinations of hydrogen with carbon, termed hydro-carbons.

We have, therefore, in the language of the meteoric chemist, siderites, those which contain iron; aërolites, those which are chiefly stony; siderolites, which are mixed, half stony, half iron and nickel: and then again the carbonaceous group. Coming from this generic chemical grouping, a word may be said as to their appearance. And here, if you will read (for I cannot go into this question in any great detail) the writings of Maskelyne and Sorby, you will become acquainted with some most extraordinary facts and coincidences. Some of the meteorites are stated to exactly resemble volcanic bombs; others resemble volcanic tufa; others again bear evidence of having being subjected to actions which we know nothing whatever about in this earth of ours. Mr. Sorby, for instance, has gone so far, and I have no doubt perfectly justifiably, as to state that in some meteorites which he has examined microscopically there is evidence to show that they were formed in a region where, so to speak, there was no gravity; that is to say, far away from the surface of any such body as the sun or our earth. When we come to the actual chemical elements which these meteorites contain, we find ourselves in a region where knowledge is extremely rich, compared to what it is at present in the case of nebulæ and comets. It is anticipating matters somewhat, but it is worth while to state that the complete list of the metallic elements of meteorites is almost identical with the complete list of metals in this list

(Table of Elements contained in the Sun, page 136). It is more than a coincidence, I think, that the chief metallic constituents of meteorites are almost identical with the chief metallic constituents of the sun. But strange to say, this is by no means the case when we come to leave on one side the metallic elements and come to the metalloidal ones, such as carbon, and sulphur. Up to the present moment there is no published observation of the existence of any metalloid whatever in the sun's atmosphere. That does not say they do not exist; but at present we know nothing definite as to their existence.

Given these meteorites, and assuming them to be the meteoric swarm which Schiaparelli postulates for the comets —that is to say, supposing that we see first in the heavens a body which we call a comet, observe it with the spectroscope, and get from it the spectrum of hydro-carbon; and then suppose that subsequently this very same body, consisting, according to hypothesis, of a swarm of meteorites, comes into our air and gives us the appearance of falling stars, and probably also the occurrence of a fall of a meteorite or two, —what would most probably be the source of the luminosity? As a matter of fact what we do see when these bodies enter our atmosphere and are rendered incandescent by arrested motion, in the manner which I have already referred to, are spectroscopic indications of the existence of sodium. The bright yellow of a falling star is due to incandescent sodium vapour, sodium being that among the elements of all meteorites which is most volatile as a metal. Next after that, in the cases where brilliancy is extreme, and where the yellow colour of the falling star gives place to brilliant white or even to a dazzling bluish white, we get added to sodium indications of magnesium. And after that, in the case of falling stars brighter even than those which I have already supposed, we have added to the sodium and the magnesium unmistakable traces of iron vapour. Now, this shows us very distinctly that if—I say if—according to this hypothesis, we really do get as falling stars what we get as the head of a comet, the temperature of a comet is much less than the temperature of the falling star while it is passing through our atmosphere, because in the comet we only get a temperature high enough to render the most volatile constituent, hydro carbon, incandescent, whereas we have passed that stage altogether when the meteorite comes into our atmosphere and the incandescence of hydro-carbon is replaced

by the incandescence of magnesium, sodium, and iron vapours. There is, therefore, abundant proof on this hypothesis that the temperature of a falling star, when it is passing through our air, is higher than the temperature of that same mass of matter when it formed part of the head of a comet.

There is one point to which I think I may be permitted to draw your attention, although at present it rests merely upon an unendorsed observation of my own. I thought it would be worth while to try what would happen if I enclosed specimens of meteorites, taken at random, in a tube from which I subsequently exhausted the air by a pump. After the pumping had gone on for some considerable time, of course we got an approach to a vacuum; and arrangements were made by means of which an electric spark could pass along this apparent vacuum, and give us the spectra of the gases evolved from the meteorites. Taking those precautions which are generally supposed to give us a spark of low temperature, and passing the current, we got a luminous effect which, on being analysed by the spectroscope gave us that same spectrum of hydro-carbon which Mr. Huggins, Donati, and others have made us perfectly familiar with as the spectrum of the head of a comet. There then we get the atmosphere of meteorites, not necessarily carbonaceous meteorites, but meteorites taken at random; and this atmosphere is exactly what we get in the head of a comet.

Now let me go one step further; and to take that step with advantage, allow me to refer to another point noticed in the last lecture, which was this—that whereas Schiaparelli had connected meteorites and falling stars with comets, Professors Tait and Thomson, on the other hand, had connected comets with nebulæ, both of them being, according to those physicists, clouds of stones. Now how was one to carry these spectroscopic observations into the region of the nebulæ? A Leyden jar was included in the circuit, and we had what is generally supposed to be an electric current giving us a very much higher temperature than we had before. What then was the spectrum? The spectrum, so far as the known lines were concerned, was the spectrum which we get from the nebulæ; for the hydrocarbon spectrum, which we get from the atmospheric meteorites at a low temperature, was replaced by the spectrum of hydrogen; the spectrum of hydrogen coming of course from the decomposition of the hydro-carbon, with the curious but at present unexplained fact that we got the spectrum indications

of hydrogen without indications of carbon. In my laboratory work I have come across other curious cases in which compound vapours when dissociated only gave us one spectrum at a time—by which I mean that in a vapour consisting of two well-known substances, under one condition we only get the spectrum of one substance, and under another condition we get the spectrum of the other substance alone, so in others again of both combined. The evidence seems therefore—though I do not profess to speak with certainty—entirely in favour of the ideas of Sir William Thomson and Professor Tait on the one hand, and of Schiaparelli on the other. I note this because I shall have again to refer to the conclusion to be drawn from it, namely, that there is probably an intimate connection between nebulæ, comets, meteorites, and falling stars.

The Stars.

Concluding what I have to say with regard to the first great group of the heavenly bodies, namely, that group which we can study by means of the radiation of light apart from absorption, I will now take up the next class, consisting of those bodies which we study by absorption.

What do I mean when I say those bodies which we study by absorption? I mean this—that whereas in the case of the radiation of light the vibrating molecules directly communicate with us and set in motion the ether which ultimately comes to our eyes; in absorbing bodies, on the other hand, the vibrations which we study have been set in motion not directly, but by the intrinsic vibration of other bodies further from us and more violently agitated than the vapours themselves, In other words, if you assume a mass of matter which is competent to give you every wave length of the spectrum—that is to say, a continuous spectrum, and if you assume around it individualised vapours at a lower temperature, those vapours, although they cannot be studied by their radiation, if they are not hot enough to allow their lines to be seen as bright lines on the bright background of the continuous spectrum, can still be studied by their absorption, because they are made to vibrate by those wave lengths given off by the interior mass passing through them with which they can synchronise. Therefore we pass from those celestial objects which we study by

means of their bright lines, to those other bodies which we study by their dark lines; we pass from radiation spectra to absorption spectra.

What bodies in the skies then can we get at by this means? We have already, by means of radiation, been able to gather several secrets from nebulæ and from comets, which are the objects which we can study by means of their radiation alone. The most numerous class of bodies in the universe, so far at

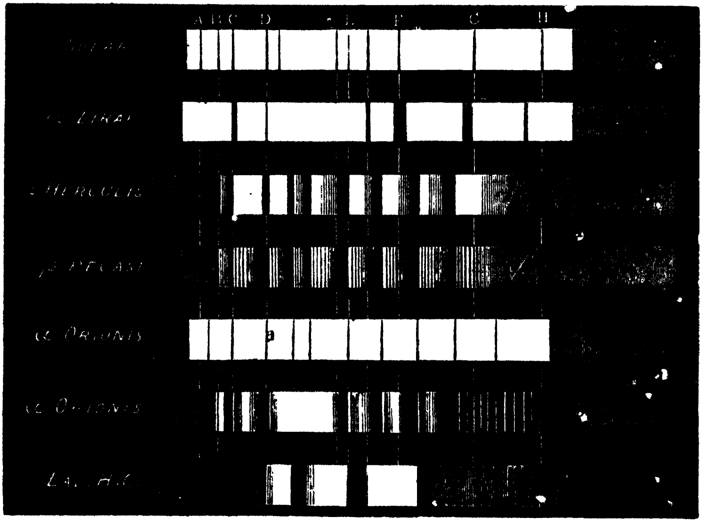


FIG. 11.—Various types of stellar spectra.

all events as we are able to grasp the universe, are what we term the fixed stars, including, of course, our sun.

In order to make my meaning quite clear, I will throw upon the screen a drawing which we owe to Father Secchi, which will give you at one view several typical spectra of the fixed stars. When we pass from the nebulæ and the comets we pass from bodies which have almost identical spectra in each case to bodies in which the spectra are very different. This diagram shows us the different classes into which the series may be grouped the moment we put this spectroscopic question

to them: What lines have you in your spectrum? or What channelled spaces have you in your spectrum? We have at the top, you see, the spectrum against which is written the word "solar;" and that means that we have there in our sun a representation of a large number of stars, which, be it also remarked, may be large or small, for this classification apparently does not hold good for the different magnitudes.

Then, again, we have a spectrum which is common to a great number of the most brilliant stars in the heavens; and the difference between that spectrum and the upper one is that it has a much smaller number of lines, and that these lines are thicker. Another spectrum is somewhat like the solar spec-

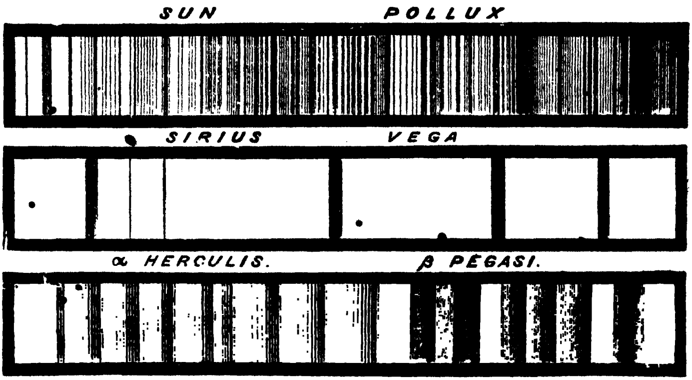


FIG. 12.—The three chief types of spectra seen in more detail.

trum, so far as the number of lines is concerned, but some of the lines do not agree in position with the lines in the solar spectrum. Now, in the three spectra to which I have already called your attention you see that we have unmistakable line-absorption; and, in the light of what I ventured to bring before you in the last lecture, I hope you will quite understand that we have evidences in the atmospheres of those stars that the elements are broken down to their ultimate degree of fineness. But when I call your attention to the other four stellar groups, you will find it is no longer a question of line absorption; instead, indeed, of a spectrum, resembling the spectrum of calcium and iron, which I showed

you, in the last lecture, we have now most distinct channelled spectra, which will remind you of that beautiful photograph of carbon. That carbon vapour we know was more complicated than the calcium vapour and iron vapour with which it was mixed. We have then, so far as this diagram can show us, different kinds of absorption going on in the stars; so much so, that we can divide the stars into groups, first, according to whether or not their absorption is the line-absorption or the channelled-space absorption; and then, again, according to whether the absorption is indicated to us by many thin lines or by few thick ones. I have another diagram here which will enable us to go somewhat more nto detail. This diagram we also owe to Father Secchi. It

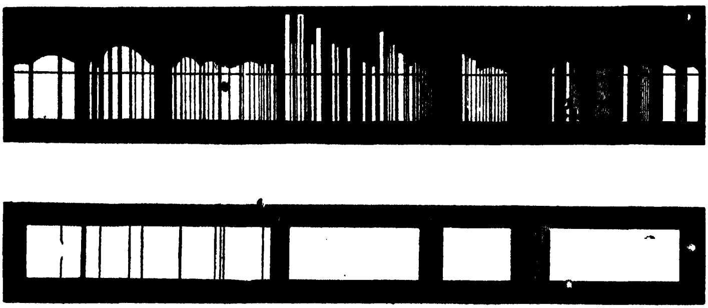


FIG. 13.—Spectrum of α Orionis compared with that of Sirius.

shows you with what extreme care this kind of observation has already been commenced and what detail has already been acquired. We have in the upper part a drawing of the spectrum of α Orionis, from which you will gather that the first drawing which I brought to your notice was only intended to give you the generic differences between the star classes, and not the special differences. Difference between a star of the type of the sun and of a star of the type of Sirius becomes much more clear and definite when we have the opportunity of observing the enormous number of lines in the stars of the sun type and the comparative freedom from lines of the stars like Sirius and Vega. In order to enter still further into detail in the case of the nearest star, I

will throw on the screen a photograph of a large part of the solar spectrum, which we owe to Mr. Rutherfurd of New York. This will indicate to you the extreme importance of getting the sun to do as much work for us as it can in the way of recording its own chemical constitution by means of photography. This photograph is on such a scale that in order to include a small portion of the spectrum it has been necessary to give it in five successive strips, the less refrangible lines being to the left at the top, and the most refrangible to the right at the bottom. Now, the chemical constitution of the sun and stars, so far as the detail is concerned, consists in finding out, as I am sure you all know, to the absorption of what particular element each of these lines is due. Now there, for instance, in the line F, we know that we have to do with hydrogen. We know that in the line near

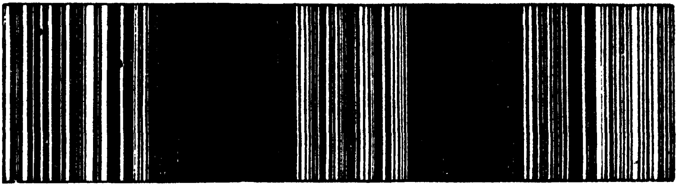


FIG. 44.—Copy of a photograph of the solar spectrum in the region of the thick calcium lines, by Lockyer.

G we have to deal with hydrogen again, and that a great many of these very complex lines about G are due some of them to iron, some to calcium, and some to strontium, and so on. Coming to the extreme limit of the visible spectrum, we find lines thicker than all the rest, and those lines we know to be due to calcium. The reason those lines are apparently thicker than all the rest seems to be that probably there is more calcium than anything else in that particular part of the sun's atmosphere where this absorption takes place.

Now that remark opens up the kind of inquiry which is possible to us when we wish to inquire into the chemical constitution of the stars. We have the position of the lines, the number of lines, and the thickness of the lines; and, let me add, when we get definite evidence of change, we want to know the change in the thickness of the lines. Now, when

we come to deal with the first class of stars, the brightest and the bluest in the heavens—stars such as Sirius and Vega—much brighter and probably therefore hotter than our own sun—we deal with the extremest simplicity of chemical constitution. We seem to be dealing almost entirely with hydrogen alone. I say almost entirely, because there appear in the best instruments traces of sodium and magnesium—those metals we have already been familiarised with by our reference to meteorites—in addition to the hydrogen; but that simplicity of construction of the spectrum which you saw on the screen, and the thickness of the lines, taken in connection with the position of those lines, indicates to us that the atmospheres of those stars are composed to very great extent of hydrogen.

When we pass to the stars of the second class, such as our sun, the chemical complexity is very much greater. If we take the sun as a type of stars of the second class, many of the elements present in its atmosphere have been determined with almost absolute certainty:—

TABLE OF ELEMENTS IN THE SUN.

Coronal Atmosphere	1474 stuff (new element ?) Hydrogen, sub-incandescent.
Chromosphere . . .	Hydrogen, incandescent Helium (new element ?) Calcium Magnesium.
Spot Zone	Sodium Titanium Chromium ? Aluminium.
Reversing Layer .	Iron Manganese Cobalt Nickel Copper Zinc Potassium Strontium Barium Cadmium Lead.

Besides which there are indications that other metals may soon be added to the list, vanadium for instance. The stars then

of the second class, of which our sun is one, have atmospheres composed of these elements. Here, as in the case of the meteorites, our knowledge is already great and is rapidly increasing; but when we come to the red stars, to the stars which give us channelled space absorption, there up to the present time our knowledge has been extremely limited. We have not been able to study the molecules of elementary bodies and compound bodies under those conditions at which they give us the channelled space spectra to such an extent as we have been able to study them under those conditions at which they give us line spectra. The result is therefore that when we come to the third class of stars with these channelled spaces, science at the present moment recoils, and is compelled to say that she does not know of what the atmospheres of these stars is composed. But again, in the light of the photograph which I showed you in my last lecture, we can come to certain very definite ideas. For instance, we have no difficulty in coming to the conclusion that the star in which we get the channelled space absorption must be cooler than the star in which the absorption is of the line kind. It is not at all impossible that science, by taking an entire survey of the whole of space, may, in not a very long period, be in possession of such facts as apparently she could only have acquired by having been present in all points of time; we may get, in fact, from different regions of space, conditions which have happened to the same body at different epochs of time; and already it is not, I think, too much to suggest that when we get a star with a channelled space absorption we have got a cooling star, the absorption of which must once have been of the line kind; therefore the stars which now give us line absorption as they get cooler must give us channelled space spectra, and so on till they become dim and cease to give us light altogether.

All of you, I am sure, have been struck, one night or another in your lives, with the exquisite colours of some stars. There is no sameness in Nature. The colours of the stars are not so well seen in Manchester or in England generally as they are in the tropics and in more favoured lands; but still we do, if we take the trouble, easily see evidences of the most beautiful coloration amongst these celestial bodies. Nor is this all. More careful observations of the stars make it absolutely clear to us that they vary very much in the light which they give out; and it is also known that the variation

of colour may go on *pari passu* with the variation of their light. We owe the first important suggestion on this point to Angström, who showed that if in the atmosphere of a star we imagine the molecules at what we may term the critical point, and suppose them to be in a condition of heat which enabled them to give the line spectrum, and also near that reduced temperature and possible association at which they could give the channelled space absorption, a very small reduction of temperature would at once change utterly the amount of light given out by that star. For instance, if you assume that stars of the third class were once stars of the second, we know that if the change could have taken place suddenly, it would have appeared as if these stars lost a great deal of their light, and that the yellow light was gradually changed to red. Now the variability of stars can go to such an extent, as I have already hinted, that a star will go out altogether, so far as our powers of seeing it are concerned. And again we may perceive a star in a region of the heavens where a night before no brilliancy was visible. How can we account for this? So far as the physics of the stars are concerned, the merely chemical considerations would at once explain to you how it was that a star should by and by lose its light. The cooling of the atmosphere, and the consequent increased absorption of the molecules of that atmosphere, as they got more complicated by the reduction of temperature, would be quite sufficient to stop all light which came from the nucleus. When we inquire how it comes that a star may suddenly shine out where no star ever shone before, there the law of uniformity, the law of continuity, does not come to our rescue so well as it does in the first case. We do want there something like a catastrophe. You recollect that a few years ago Dr. Huggins was enabled to make a most important series of observations on a star which broke suddenly into intense light and then faded away into the utmost bounds of visibility. Now there it was found that the light of the star, changing as it did, gave rise to perfectly different spectrum effects. That star when it was only of a certain definite brightness, as it was at first seen, gave us a spectrum with dark lines similar to those I have thrown on the screen; but when its maximum brilliancy was reached, the character of the spectrum changed—a spectrum of bright lines was added; and then we had an indication of a new class of bodies, namely, those bodies which we study both by their radiation and absorption. So much for the facts.

THE SUN.

We will now pass to the sun, so that we may be able to build any conclusions with regard to the causes of these phenomena in the case of the more distant bodies on somewhat firmer foundations than we could have done had we not this big star close to us to refer to. In the first place, I would like to show you that the statements which have been made with regard to the chemical constitution of the stars rest upon a basis sufficiently firm to justify me in bringing them before you. Dr. Huggins, who was the first to observe the spectra of the stars in a manner which left nothing to be desired, so far as eye observations were concerned, made comparisons of the dark lines of the stars with the bright lines of the different elements in the same instrument at the same moment. A very small addition to that method, namely, the introduction of photography, enables us not only to do this, but to make a record which is good for all time. I propose therefore to illustrate the method by throwing upon the screen two photographic comparisons, the object of which was to determine which were the lines I have already shown you in the solar spectrum, which were really due to the vibration of the particles of iron vapour in the atmosphere of the sun. For that purpose all that one had to do was first to photograph the spectrum of the sun, and then on the same plate and by the same instrument, under absolutely the same conditions, photograph the spectrum given by the iron vapour. You will see the result on the screen. Of course such a photograph has to be made for every chemical element the existence of which in the sun we wish to study. I may remark, in passing, that the only difficulty in illustrating this kind of inquiry is the impossibility one labours under of ever getting a chemical substance which is absolutely pure. We have now on the screen, on a very large scale indeed, that part of the solar spectrum which in Mr. Rutherfurd's photograph was to the extreme right at bottom. Here are the two calcium lines which you saw before, and which are much thicker than any other lines in the spectrum. The dark lines are the regions where there is no light to paint the image of the slit in consequence of that light having been absorbed by the iron vapour in the atmosphere of the sun; and above these dark lines you have the images of the slit painted by

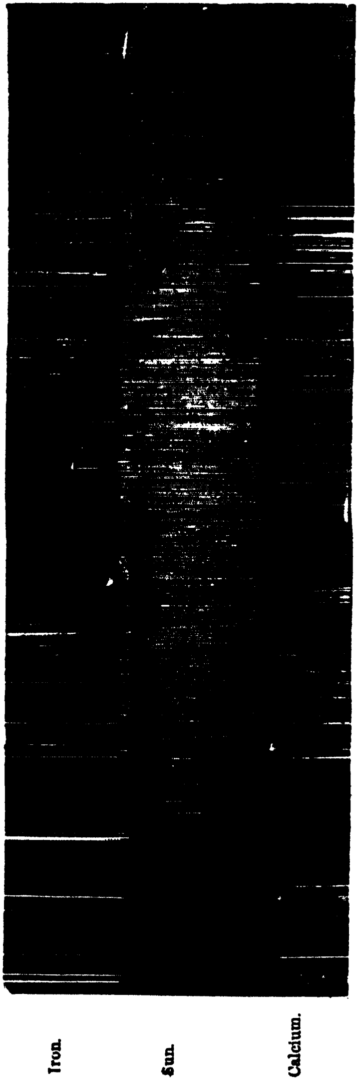


FIG. 15.—Comparison of the absorption spectrum of the Sun with the radiation spectra of iron and calcium, with common impurities. Copy of a photograph by Lockyer.

the vibrations of iron vapour, not in the sun's atmosphere, but in a laboratory at South Kensington. If you will take the trouble to compare the more definite lines you will see that there is a perfect coincidence between the bright lines and the dark ones which are caused by the iron vapour of the sun.

The next diagram[1] is, if anything, more interesting still. In this one we are dealing not with iron but with manganese. We have, you see, bright lines coincident with the dark lines of calcium, but these are due to calcium impurities. I am anxious to call your attention to a group of four lines in the solar spectrum and a broad band of light, corresponding with these in the spectrum of manganese. There are three bands of absorption on this band exactly coinciding with the three more refrangible lines in the solar spectrum to which I have drawn attention; that is to say, we not only in that photograph get absolute proof that those four lines in the solar spectrum are due to absorption at the sun by vapour of manganese, but we get the vapour of manganese in a laboratory doing for the more incandescent manganese what the outside sun does for the inside sun; we have in fact the cool vapour of manganese around the incandescent manganese giving us *nearly* the same absorptive effects as the manganese vapour does at the sun.

So much then for the method of acquiring these chemical facts. If we merely had that method, we should be able to say that certain substances exist in the sun; but that would scarcely be enough. We don't want to know merely that such and such substances exist in the sun or in a distant star; if possible, we want to know whereabouts in that star the particular substance lies. Now for that purpose we have to consider these spectroscopic results in connection with the telescopic results. What I mean by telescopic results will be brought before you by throwing on the screen in the first place a photograph of the sun which again I owe to the kindness of Mr. Rutherfurd of New York. Here is the sun on an enormous scale, photographed by itself.

The Chemistry of Different Portions of the Sun.

Now if instead of observing the sun as ordinarily visible, we observe it during an eclipse, we find that the sun that we see is only the small interior nucleus, so to speak, of the true sun,

[1] This photograph is not given, but the same effect may be noticed in Fig. 1 in the case of the thicker lines of calcium and aluminium.

and the reason we see the interior nucleus alone is because it is so very much more bright than the surrounding atmosphere. This photograph (Fig. 16) was taken in India in 1871. When we get the dark moon exactly between us and the brighter interior sun, there is no difficulty whatever in seeing that there is an atmosphere with its own characteristic effects, extending to a considerable distance above what we consider the sun ordinarily speaking (Fig. 17). So that you see telescopically we can make a complete distinction between one part of the sun and the other.

Now the question is, can we spectroscopically determine in what particular part of the sun each of these elements exists?

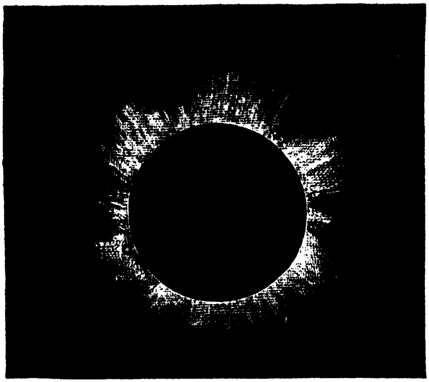


FIG. 16.—The Sun's corona, from a photograph taken in 1871.

Here is another drawing, which shows you what happens when we observe the region intermediate between the two I have shown you. The first drawing brought before you the photosphere of the sun; the second drawing brought before you the corona—the name given to all the exterior of the sun. At the base of the coronal atmosphere, that is, just above the photosphere, we have a region which has been named the chromosphere, in which certain strange forms are to be seen, and which are here shown (Fig. 18) from a drawing by Professor Young. These have been called "prominences," or "red flames."

So that we have the photosphere underlying part of the sun's

atmosphere and above all the coronal atmosphere; resting in the middle, so to speak, this chromosphere and its prominences; and then between the photosphere and the base of the chromo-

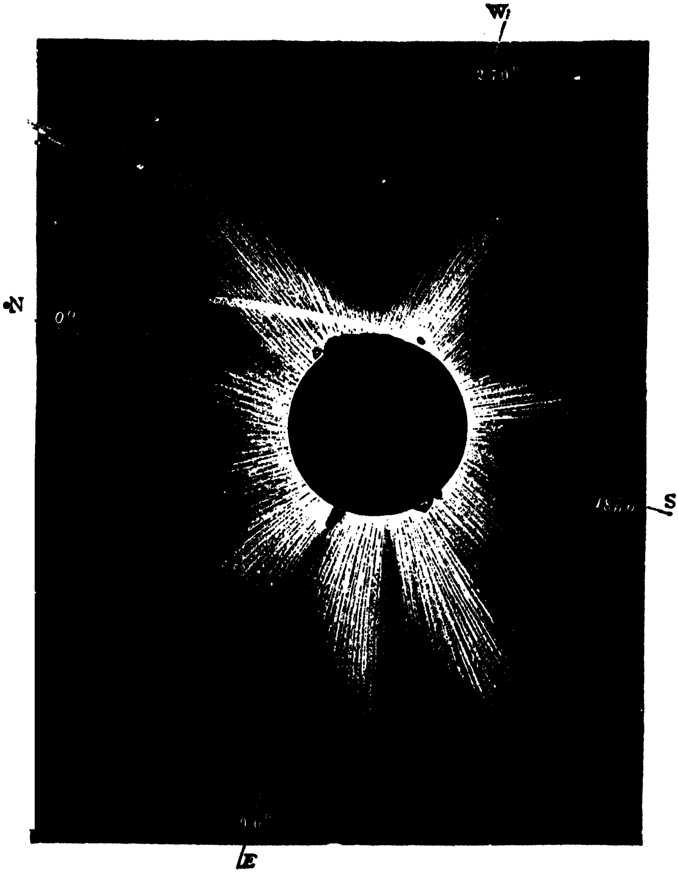


FIG. 17.—The Sun's corona and prominences, sketched during the eclipse of 1868.

sphere an extremely thin layer where most of the absorption takes place. Now this thin layer has been called the reversing layer, because it is here that the sun's light is reversed and

the Fraunhofer lines produced; so that the statements generally made as to the chemical constitution of the sun and stars really refer to this particular film—for film it is, in comparison to the size of the sun—lying between the chromosphere and photosphere. We have, therefore, the photosphere, reversing layer, chromosphere and coronal atmosphere, into which, if we can, we may sort out the different elements.

Now this is what has been done, and the results are shown in the table (page 136).

If you imagine an arrow shot into the sun, it would first pass through the unknown element of which the upper part

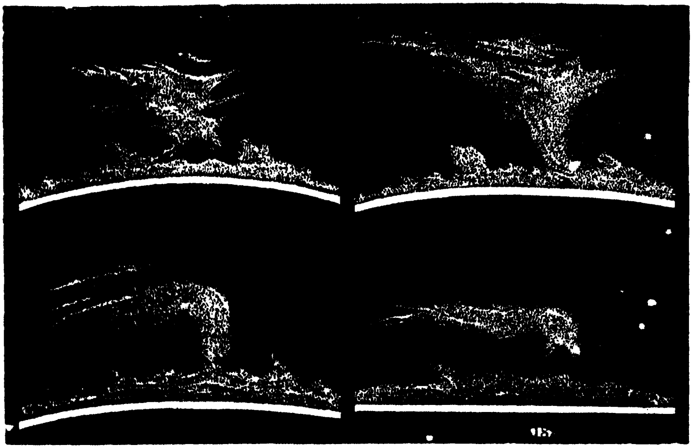


FIG. 18.—Young's drawings of prominences.

of the coronal atmosphere seems to be chiefly composed; it would then come to the region where practically there is hydrogen and nothing else; getting into the chromosphere you come to another new element, and then in the reversing layer you get magnesium, calcium, sodium, &c. At length we come to traces of some substances which either exist there in very small quantities or lie at a much lower level than the others.

For one of the important teachings of this work seems to be that at the great temperature of the sun—a temperature which brings about a dissociation much more complete than

anything we can obtain here even by electricity, unless perhaps we use the most powerful induction coils—there is the same magnificent order, though it may not be fully known, which exists throughout nature, and we find hydrogen thinning out at one level and magnesium thinning out at another, and so on; and I have suggested that the system of strata produced by this thinning out may be connected with the true vapour densities of the elementary bodies.

With regard to magnesium and calcium, I should remark that the list, made in 1874 will most probably have to be revised, as one of the results of the Eclipse Expedition to Siam in 1875;[1] for although in all past work on the sun it was impossible to determine whether magnesium or calcium was highest, the Siam observations seem to add to the probability that calcium really lies above magnesium; in other words, that the true vapour density of calcium is less than the true vapour density of magnesium. This reference to vapour densities will in the next lecture bring me into complete *rapport* with Professor Roscoe's lectures on the chemical structure of the earth's crust.

THE PLANETS.

There is still, however, another large group of bodies to be considered—I refer to the Planets—before we have exhausted the bodies external to the Earth. Although, however, this group of bodies is numerous, we have not very much to say about them, for a reason which I am sure you will easily appreciate. When we deal with the radiation of the heavenly bodies, we are dealing with a condition of vibration of particles of those bodies at their utmost fineness, so that each vibration comes to us with a story to tell as to the actual chemical constitution of that body. Then when we come to that large class of objects which we study by means of absorption, there again we have the same molecules doing the same thing, but instead of giving us vibrations of their own, they absorb other vibrations which were attempting to pass through them. But when we come to the planets, we come to bodies like our own earth; bodies comparatively cool; bodies not in a state of incandescence, where matter is not as a rule in a state of gas or vapour, but

[1] I have done this in the table as given.

in the solid form. We come therefore to bodies which can neither radiate nor absorb light, in the sense in which we have dealt with radiation and absorption; because, in consequence of the reduction of their temperatures the chemical elements have compounded; we have not the individuality which is requisite; we have not the discrete particles, but combinations of every complexity. As the result of that, what is our only chance of seeing them at all? We see them by reflected light. The bodies now under consideration, unlike the nebulæ and comets, and unlike the stars, reflect light to us, and only by the reflection from their surfaces can we tell that they exist. Now as all bodies, whether they are solid or liquid, are spectroscopically dead, so to speak, so far as getting chemical information from them is concerned, inquiry is perfectly useless excepting in one particular—it proves that it is powerless, by showing that the light of the sun is so faithfully reflected by these bodies, that all the principal lines of the solar spectrum are to be found in it. It is true that there are exceptions in the case of the exterior planets of our system, especially in Uranus and Neptune. In the spectrum of those bodies, cool though they are, like our own, in addition to a constant absorption of the sun's atmosphere and the earth's atmosphere, a third absorption of the atmosphere of the individual planet is indicated. With that exception, you will see that the spectroscope is powerless to help us. How then can we hope to get at the chemical constitution of the planets if the spectroscope does not come to our assistance? There is, I fear, only one chance for us, and that is to determine, as nearly as may be, the densities of these bodies, and to see if it is possible to find out anything to reason upon when these densities have been thoroughly well sifted. Now we do know already with some accuracy the density of the planets. We know that these planets may be broadly divided into two groups; we have the interior group, of which the Earth is one—Mercury, Venus, the Earth, Mars—small heavy planets. The density of the earth is about five and a half times the density of water. The density of these interior planets you may say, roughly, is the same as the density of the earth; therefore we have this group of interior planets with a density of five and a half times that of water. After this we have a considerable gap, a gap partly filled by the minor planets or asteroids; and after that we get another group—Jupiter, Saturn, Uranus, Neptune—not small and dense planets like the Earth, but enormous

light planets, having, roughly speaking, and on the average, about the density of water. So that the density of the interior planets is to the density of the exterior planets about as five to one. Now if this density were known to be associated, in the case of the planets I have named with equal solidity from centre to circumference, of course we should be able then to form a rough idea as to their composition. But we do not know that. But still let us, if we can, carry the inquiry into the secondary bodies of this system—into their satellites.

If we take the only case in which facts approximately accurate are at our disposal—the case of Jupiter—we find that if we take the density of the satellites of Jupiter to be on an average one, the density of Jupiter is five, and the density of the Earth as an interior planet would be twenty-five; so that the outside planets of our system are one-fifth the density of the inside planets; and in the only case where we have a complicated system of satellites, that we can deal with, we have exactly the same relationship there, and the satellite is only one-fifth of the density of the planet itself.

I hope to have the opportunity next week of pointing these remarks by reference to what I have already brought before you, especially to the condensation of the nebulæ and to the particular position which each chemical element occupies at the present moment in the atmosphere of the sun.

WHY THE EARTH'S CHEMISTRY IS AS IT IS.

LECTURE III.

In the latter part of the last lecture I referred to the different densities of the two great planetary groups. We saw the interior group of a density, roughly speaking, five times greater than that of the exterior group; and taking the satellites of one body in the exterior group, we found the same relationship of density; the primary being five times as dense as the secondary body, which in that case was one of the satellites of Jupiter.

Now the fact that the Earth is one of the interior group of planets leads us to assume (and I pointed out to you that assumption is almost the only thing left to us in regard to estimating the chemical relationships of the earth) that probably the chemical constitution of the earth is similar to that of the planets which form the interior group—Mercury Venus, the Earth, and Mars. Now if we look upon the planets from another point of view, if we consider the extent to which some of them are flattened at the poles, we find the same grouping as we did before. The interior planets are flattened very little at the poles, as compared with the flattening of the exterior bodies. Now this flattening has been very beautifully experimented upon by Professor Plateau: and, thanks to Mr. Binyon's skill, I hope I shall be able to throw on the screen some of the phenomena to which Professor Plateau refers. When it is a question of investigating the flattening of a planet experimentally, the first thing one has to do is to take away the influence that gravity might have on the body experimented upon; and Professor Plateau very ingeniously did this by making the rotating body a mass of oil in a mixture of spirit and water of precisely the same specific gravity; so that the mass of oil in the centre was neither inclined to rise nor fall, if the mixture had been

properly made. Here we have on the screen an image of such a mass of oil and a disc connected with a spindle, which we can cause to revolve somewhat rapidly. The revolution of the spindle is communicated to the oil by means of the disc, and what we find is this (supposing the experiment to be perfect). With a certain amount of rotation, the spherical form of the oil first changes into a spheroidal one; as the rotation is increased we get a flattening—as the mass of oil is compressed in one direction it is extended in the other—and we get the equivalent of what we have in the Earth which we describe by saying that the equatorial diameter is so much greater than the polar diameter. When we are able to repeat this beautiful experiment under the best conditions, we find that after a certain point, the oil is not content with expanding in one plane; it is not a question of shortening one diameter and increasing another, but under one set of conditions the oil can be made to form a complete ring, absolutely perfect and disconnected from the central disc; and when the rotation of the central disc is slackened, the oil then comes back again and re-forms, so to speak, a miniature planet. That is one case. Another case can be studied by commencing the rotation with somewhat greater rapidity; and what happens then is that, instead of getting the formation of a ring, the oil is broken up and thrown off in tangents, forming a kind of spiral. Those are the two main classes of phenomena which can be observed in this way.

The inferior group of planets has a day almost entirely the same as ours—a period of rotation of about twenty-four hours. The period of rotation of the exterior planets has not been determined in the case of the two exterior ones, Neptune and Uranus; but we do know that in the case of Jupiter and Saturn the rotation is accomplished in less than half the time taken by the members of the interior group.

What, then, are the facts with regard to these planets and their flattening? I am able, by the kindness of several friends, to throw upon the screen some very beautiful drawings of all the planets which I have mentioned; and I want you to be good enough to look at these drawings from two or three points of view. First, I want you to see the difference in the amount of the polar compression in each case; and, for future reference, also the difference in the atmospheric effects. We will begin then with the planet which is most similar to our own, the planet Mars.

You will see that it has markings similar in kind, no doubt,

FIG. 19.—Mars; south pole visible.

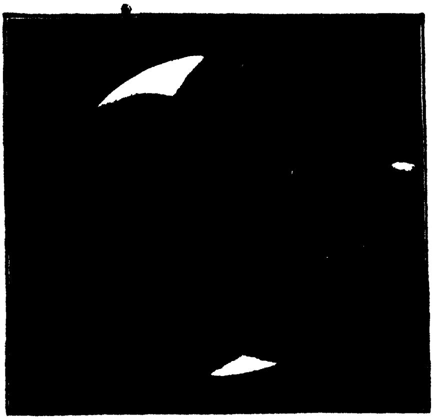


FIG. 20.—Mars; both polar caps visible.

to the markings which would be seen by the spectator observ-

ing the Earth from the Moon. You will see also that its compression is small—in fact, I may say, that it is not to be appreciated at all. Here are three drawings of Mars, made by the distinguished Dutch astronomer, Kaiser, of Leyden. You see that there is no polar flattening. That the upper part represents the true pole of the planet is rendered evident by the fact that you have there a snow cap at the south pole. There again you have the snow cap; and here in these dark markings we have seas. The Earth's place then, in Nature, both as to polar compression and atmospheric condition, is evidently very similar to that of Mars. When, however, we go

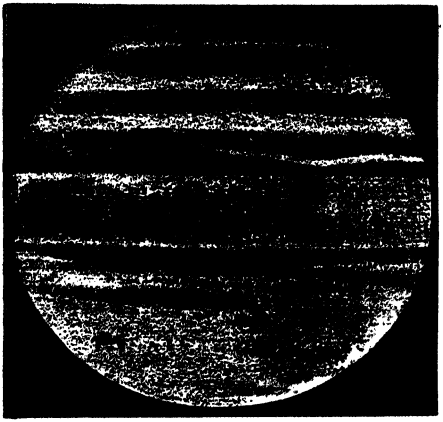


FIG. 21.—Jupiter.

from Mars, which is the only member of the interior group, excepting the Earth, about which we can say anything with decision, we see that all the phenomena are considerably changed. We pass from a density of five to a density of one, and the twenty-four hours day or thereabouts of Mars is now replaced by a day of something like ten hours in the case of Jupiter, the planet which comes next in our survey. Here we see how much shorter the polar diameter is than the equatorial one. You will be reminded by these cloud-belts of the much more simple system of cloud-belts which traverses our own Earth near the equatorial regions. There is little

doubt that the darker portions here are the portions of the atmosphere of the planet freest from cloud, and it is especially in this region that an observation to which I shall presently have to refer was made. Going then still outwards, we come from a compression of considerable magnitude to a planet in which the compression is somewhat less. But you will see, that although the polar compression is somewhat less, we have what I termed an "extreme case," when I was referring to Plateau's experiment. We have in the planet before you (Saturn) exactly the condition which was observed by Plateau in his experiments with the oil and mixture of spirit and water. We have traces of clouds, as in Jupiter; but the all-absorbing feature in the case of Saturn is this wonderful ring, about which observations are, fortunately for science, being very rapidly accumulated, showing that considerable changes are going on in it.

We now know that we are in presence of a ring, or rather an infinite series of rings, of, let us say, meteorites, small satellites of Saturn, out of which at some future time larger satellites will be compounded. This is one of the most beautiful results of modern thought and work. Laplace, who first considered the question of the mechanics of the rings, which were in his time considered to be solid, was content to leave them solid, provided the rings were very numerous and that the centre of gravity of each was not coincident with the centre of gravity of the ball; but modern mathematicians, among whom must be specially mentioned Peirce and Clerk Maxwell, have shown that the rings cannot be solid and cannot be liquid, and in short such a structure as that referred to above is the one now required by mathematical theory. Such a structure, moreover, is the only one which fits the facts. The brightness of different portions, the variations in brightness and breadth of each bright or dark part, the gradual widening of the whole system—29 miles a year according to one estimate—and many other facts are thus easily explained. Some recent observations[1] made by the Washington 26-inch equatorial not only establish important changes which have recently been going on, but afford further evidence of the meteoric structure of the strange appendages, *e.g.*, the dusky inner ring is not now perfectly transparent as it once was, the planet can only be partly seen through it, while the matter composing it is agglomerated here and there into small masses, which prevent the planet being seen. Mottled

[1] Trouvelot, Proc. Amer. Acad. 1876, p. 174.

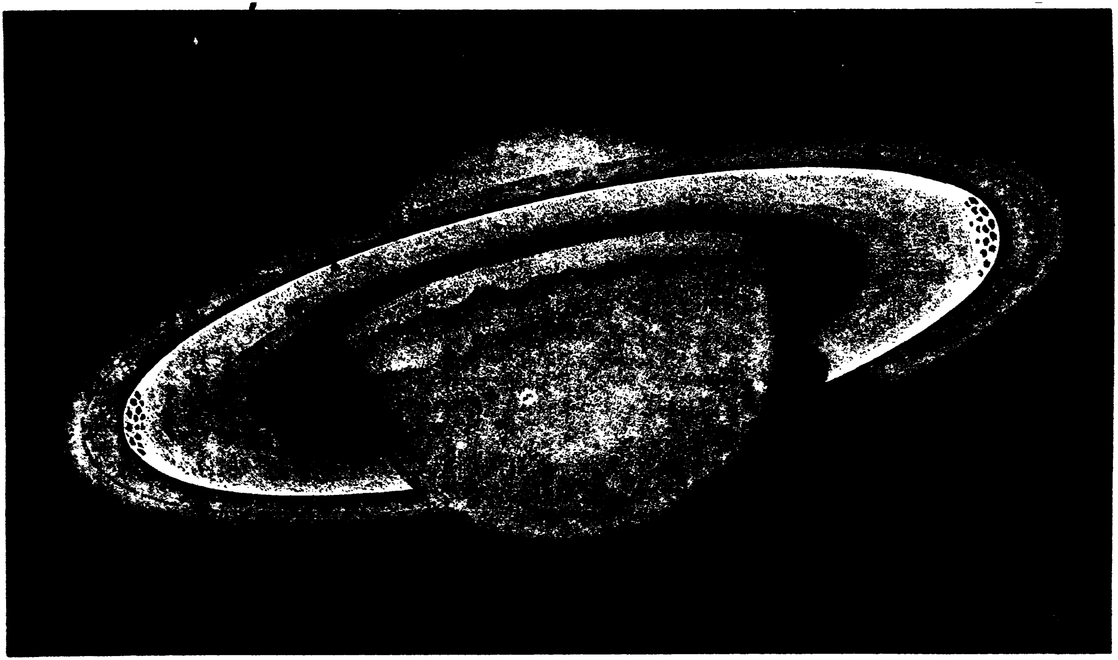


Fig. 22.—Saturn, from a drawing by Trouvelot, made by the Washington 26-inch refractor.

or cloudy appearances have also been observed on the surface of the exterior portions of the ring system during the last four years.

We must now pass from the facts relating to the physical condition of the two great groups, as it is as yet impossible by a further discussion of them to learn anything about the chemical constitution of the planets themselves. The question arises—Can we learn anything about the composition of their atmospheres? Let me remind you that we are dealing with that class of bodies which shine by reflected light. It is clear therefore that when we examine by the spectroscope the light of the sun reflected by these bodies, we shall have the solar spectrum, *plus* the spectrum due to the absorption of any special planet. Now, as a matter of fact, the solar spectrum, as observed from the Earth, is tainted by, or mixed up with, the absorption of our own atmosphere. But fortunately we can get rid of the absorption effect of our atmosphere by varying the observations so that at one time we shall have a great thickness of atmosphere, as when we observe the sun in the morning or evening, and at other times a small thickness, as when we observe at mid day; and at those times we shall have the spectrum changed, owing to this change of condition. In that way men of science have been able to separate the absorption taking place at the sun, from the absorption due to the Earth's atmosphere.

The interior planets tell us that there is absolutely no special absorption in their atmospheres. So far as they have atmospheres at all, they are undoubtedly similar to our own; therefore the Earth's place in Nature is with the interior groups of planets. But when we pass outwards from the interior group to the uttermost confines of the exterior one, when we leave Mars to go to Neptune, Saturn, and Uranus, we find that from Jupiter, outwards, there is a something interpolated into the atmosphere, so that the outermost planet has the atmosphere, which differs most from our own. Uranus and Neptune have very extraordinary atmospheres of their own, which are indicated by a very definite spectrum. Traces of the substance which gives us this extraordinary absorption in the outermost planets are also to be found in the atmospheres of Jupiter and Saturn; so that we are driven to the conclusion that the atmosphere of the exterior planets is different from the atmosphere of the Earth by the addition of a new absorbing substance to the aqueous vapour which is the only *effective* absorber in our own atmosphere.

The Question of Evolution.

I have now gone through, *seriatim*, the physical and chemical constitution of nebulæ, stars and planets, so far as the facts and the time at my disposal have enabled me. What may we say then as a general summation of these facts, brought together with a view of determining whether they throw any light on the cause of the Earth's actual chemical constitution? Physically speaking, the Earth is a cooled body, revolving round an incandescent one. Chemically speaking, its chemistry has been most admirably brought before you by Dr. Roscoe in those three lectures which we have now the opportunity of reading carefully; and its kinship with the other bodies which people space has been established by the fact of the community of elements. Dealing only with the spectra which have been observed in the nebulæ we have recognized hydrogen; in the comets we have recognized hydrocarbons; in the stars and in the sun we can tell of elements amounting to twenty-five in the case of the sun, nearly all of which elements we have on this Earth; so that it is not too much to say that one of the glories of the spectroscope has been to show that the Earth in its chemical constitution is simply a part of one of the great systems of the universe, and differs in no way from the matter which masses here as nebulæ, there as comets, and there as stars.

I have drawn your attention to the conclusions which we are justified in drawing from the facts; and the question is, Does the story end now the facts end? I hope to show you that it need not necessarily do so. A student of science endeavours to accumulate facts. Facts are the rewards of scientific work; but how, when a man of science has accumulated a large number of facts, is he best to proceed to get new ones? That is our case. I have endeavoured to bring before you all the facts, roughly, which the spectroscope has placed at our disposal with regard to the chemical constitution of those different masses of matter which people space. But how are we to attempt to get more? Are we to go haphazard at it? No. Hypothesis is the life-blood of investigation; and having an array of facts before you, the thing to do is to attempt to put them in such an order that they will suggest inquiry in special directions. Do not be afraid when I say that hypothesis is the life-blood of investigation, lest the world should

soon be filled with hypotheses. History does not bear this out; and further, a man does just as good work by destroying an unsound hypothesis as by establishing firmly a true one. Having then these facts before us, and having necessarily to form some hypotheses, what is the most general question that we can put to these facts, which tell us of the existence of nebulæ, comets, suns, planets, and the like? The most general question, I think, that we can ask is such a one as this: Have we, as the result of our inquiry, got together such facts as enable us to consider nebulæ, stars, comets, and planets as finished products, each of them gloriously, magnificently, perfect in its way; or do these merely represent, let us say, the seed, and the flower and the fruit?

Here, of course, we have to do with Evolution pure and simple; and I may remind you that it is now a good many years since two of the most profound thinkers on our planet, at the time—I refer to the German and Frenchman, Kant and Laplace—independently arrived at the answer to the question I have propounded. The answer was identical, and it was this: You have in these various bodies not finished products, each perfect after its kind, but really and truly the seed and the flower and the fruit. And the hypothesis which they put forward was something like this—that the nebulæ, representing what I told you Tycho Brahe considered them to be a true fire dust—was probably wrought into stars by means of the condensation due to gravity, which in time brought the most irregular nebulæ down to the appearance and the consistence of a star. And then Laplace and Kant, knowing well of the observations of the rings of Saturn—the experimental imitation of which I have brought before you—suggested that our planets were left behind, first as rings, while the nebula was contracting to form a star. So that if you begin, in any quarter of space that you choose, with a nebula, and give it time to work, the nebula will condense, a star will be formed, and in the process rings, which will subsequently break up and form planets which will subsequently cool, will be produced. Such then is an hypothesis which has now been before the world some years and certainly is exceeded by none in the grandeur and grasp of its conception; it was started before the spectroscope, as we now know it, was dreamt of. Do the facts which have been brought to light by the spectroscope lead us to think that this hypothesis will no longer hold water now we have got a larger area of facts to deal with, or do the new facts really

come well in and support the old and enable us to fit other parts into it?

Now, in order to deal with this question, I shall first trace the passage from the nebula to the star, which is the first part of the conception of Kant and Laplace. If you will consider the conditions at work in a nebula such as I told you Professor Tait is content to imagine it, namely, a nebula consisting of a huge cloud of stones, the luminosity of which depends chiefly upon the impact of these stones together, and I suggest in part upon dissociation of hydrocarbon—if you take such a nebula as this, and imagine it to be condensed to a star, you will see at once that the conditions of Plateau's famous experiment are exactly reversed. In the experiment, we begin with the star at rest, and the experiment is performed by setting it in motion. But in truth, if Kant was right, that experiment must be exactly reversed; rotation will be at the end of the business. We must imagine rotation set up over an immense area, rapid enough, after the condensation in a plane is considerable, to give us many rings. What Plateau saw when the matter went outwards will occur backwards, as the matter condenses inwards. Instead of rings formed and moving outwards we shall have rings formed and moving inwards, tangential outpourings will be represented by tangential inpourings. I will recall your attention to two or three nebulæ, which I showed you on a former occasion, and in the light of this hypothesis, I think you will see that the telescopic evidence is also in favour of the idea. I am now about to show you the group of nebulæ sketched by Lord Rosse, some of them having been observed in the first instance by Sir John Herschel. I do not wish to call your attention to all of them, although much might be said, I am sure, about every one; but I want especially to draw your attention to those which resemble Saturn, and are like the sphere and ring of oil in Plateau's experiment. We have in the centre a condensation; we have around it a globular mass not so brilliantly illuminated; and around it again we have a ring. There again is an object of an almost similar kind, seen from a different point of view, in which the ring is edgeways to us. I might go on taking up very much more of your time, but I don't think it is necessary to enlarge very much upon this part of the subject, after the drawings I showed you on the first occasion. It will be clear to you that

if we take this view we shall demand with each degree of condensation, with each degree of contraction, an increase in brilliancy; so that the smaller the space occupied by the materials which first constituted the nebula, the brighter and the hotter will they become. So that we must imagine that the star finally formed must be one in an intense state of incandescence; in fact, in a state of incandescence of which we cannot have the most remote notion.

What says the spectroscope? Here the spectroscope is quite at one, I think, with the idea; in fact, there are nebulæ and stars with spectra so similar that if one had the evidence of the spectroscope alone, it might be impossible to decide which was nebula and which was star. Now this may be a little startling to some of you, and therefore it is only fair I should explain it. The stars, you know, are so remote from us that in the most powerful telescopes to which spectroscopes are applied, they appear only as the finest points of light. Now these points of light, it is not absurd to imagine, may in some instances be two millions, or perhaps even three millions, of miles in real diameter. We know that our own sun, which is certainly not the largest star in the heavens, is nearly one million miles in diameter; that is to say, the true sun, the true stellar nucleus, is one million miles in diameter. Now when I dealt in my second lecture with the physical constitution of the sun, I pointed out that the sun which we see, the sun which sends us the majority of the light we receive, is but a small kernel in a gigantic nut, so that the diameter of the real sun may be, say, two million miles. Suppose then that some stars have very large coronal atmospheres; if the area of the coronal atmosphere is small compared with the area of the section of the true disc of the sun, of course we shall get an ordinary spectrum of the star; that is to say, we shall get the indications of absorption which make us class the stars apart; we shall get a continuous spectrum barred by dark lines. But suppose that the area of the coronal atmosphere is something very considerable indeed, let us assume that it has an area, say fifty times greater than the section of the corona of the star itself; now, although each unit of surface of that coronal atmosphere may be much less luminous than an equal unit of surface of the true star at the centre, yet if the area be very large, the spectroscopic writing of that large area will become visible side by side with the dark lines due to the

brilliant region in the centre where we can study absorption; other lines (bright ones) proceeding from the exterior portion of that star will be visible in the spectrum of the apparent *point* we call a star. Now it is difficult to say whether such a body as that is a star or a nebula. We may look upon it as a nebula in a certain stage of condensation; we may look upon it as a star at a certain stage of growth.

And in the fact that we have actual nebulous stars—stars which in the telescope can scarcely be defined from true stars, and spectroscopic effects such that it is difficult for us to say whether they are produced by star or nebula, we have in these two points very strong arguments indeed in favour of this part at all events of the evolution hypothesis.

So much then for the passage from nebula to star. How about the passage from star to planet? Let us, in the first instance, assume that the nebula is vastly condensed before the rings begin to form. It is difficult of course for us to say whether this is really true or not, because we know not the distance of the nebulæ; but I think you will agree that it is a fair assumption. In this case, if the condensation is excessive, and the heat due to arrested motion be excessive also, we shall have then to deal with the facts. Where in the heavens have we just this particular series of facts? We have it in the sun. We have the sun now near to us, so that we can study its constitution, still in a state of intense incandescence, and so far as that point goes at all events it may be fairly taken its represent probably an earlier stage of its growth. And the being so, I think it will be fair to take the sun as representing the closest approximation to a nebula in its last stage which is available to us. It would be better perhaps if the line between the inner and outer atmospheres were less sharp, but we must take it as it is. Now one of the most unforeseen results connected with recent solar work has been that the different chemical substances which various observers have placed in the atmosphere of the sun, are not all mixed up pell-mell, but are really thinned out into layers; so that we can not only say, when we wish to compare the chemical constitution of the Earth with the sun, that the chemical constitution of the sun is so and so, but we can say that in the chemical constitution of the sun this element occupies one position in the solar atmosphere, and that element occupies another. So that, in fact, taking the sun to represent a nebula at the time

that rings were being formed (mind you, I don't say thrown off, we must reverse Plateau's idea), the fundamental point we have to bear in mind is that if we take the sun at all, we must take it with its layers. Now here we have an opportunity which Kant had not; and here, I think, the spectroscope enables us to deal with Kant's hypothesis in a somewhat satisfactory manner. We may be said to improve somewhat upon the conceptions which were merely physical by making them slightly chemical. Now if we have these known metals placed as near as may be in this order [Table]—probably the position of the metal aluminium is the most doubtful,—we have in the first instance to account for the absence of the metalloids. I have given grounds elsewhere, and it is not necessary to repeat them to-night, for believing that the most probable position for the various metalloids in the solar economy is outside these metallic strata. So that if we take a section of the sun's atmosphere, we must imagine the metalloids to be outside if they be there at all, and then as a link between the metalloids and denser metals, hydrogen, calcium, and magnesium generally coming in that order, or thereabouts. Let us for a moment consider the sun as a nebula. There is ample evidence, I think, to show that the temperature of the nebula was then as great as the temperature of the sun is now; consequently you will have all these metals existing uncombined, the metalloids existing outside, also probably uncombined. And what happens on Kant's hypothesis?—that the nebula in starting a rotation and contracting leaves behind it its exterior portion; so that probably we may say that the first planet thrown off—let us assume that that was Neptune, although probably there are many planets beyond Neptune—must have been thrown off from the extreme limit of such a nebula, and must have been built up of those particular materials which were existing at that particular part of the nebula; *that is to say, that it is almost impossible that there should not be an overwhelming preponderance of metalloid in Neptune.* As the various rings are formed from the exterior of the nebula while the contraction is going on, they will consist chiefly of metalloids; whereas when we come nearer to the sun, they will consist chiefly of metal. Now that being so, we have two opportunities of testing the idea which has led to this conclusion. If the exterior planets are metalloidal and the interior planets are metallic—(I do not mean that one group is *entirely* metal-

loidal and another *entirely* metallic)—it will be impossible for the density of the exterior planets to be as great as the density of the interior planets. We have already found out that that density, as a matter of fact, is about one to five. This density, of course, must be lower, because we shall have the best possible conditions for high density where we get the metal in its purest state. Where the density then is least, in the case of the exterior planets, we shall find probably that the velocity of rotation will be different from the velocities of rotation of the other planets. That also, I have already pointed out to you, has been entirely answered by observation. Let us then, if we can, take this one step further. Let us take for granted that the difference between the interior planets and the exterior planets is precisely of this kind. Can we trace the same principle—can we send this chemical touch further into the hypothesis, and deal with, say, no longer the sun and the planet, but a planet and its satellite? I think we can; and I think too that in the case of Jupiter, the density of which as compared with the density of its satellites I have already mentioned to you, we have a most singular corroboration of the continuation of the sifting process.

If the facts I stated in the last lecture were accurate—and I believe they were as accurate as they may be in the present state of science—the density of the satellites of Jupiter in the main is only about one-fifth that of water. Now it so happens that one of the satellites of Jupiter, when it crosses the disc, very often puts on a very dark appearance. We have, therefore, here very good reason to infer that this particular satellite of Jupiter may probably be merely a mass of gas; and it is very possible that in the case of Neptune and Uranus we may be dealing with bodies which, for the same reason, will remain almost for ever in a semi-gaseous state. And let me remind you that this would at once explain the spectroscopic researches of Vogel and others on the atmospheres of these planets. If you have an atmosphere round Neptune and Uranus consisting of combined metalloids, we may have our choice between several possible spectra. I believe no one has yet made the direct experiment, but the description of the spectrum of Neptune given by Vogel is not very dissimilar from the spectra of the different oxides of nitrogen. That at once then would

explain the various spectroscopic differences as well as the compression difference.

I must remind you, in order to make perfectly clear what I have already ventured to bring before you with regard to the form of these rings, that of course it is assumed that after the ring has been formed it eventually breaks up. Now the facts, I think, seem to show that when this breaking-up takes place, a considerable amount of heat is produced; so that you see, if we consider the density of the exterior planets and their satellites, Jupiter, &c., and of our own Earth and its satellite, we have indications not only that this sifting, this sorting process, did really go on in the formation of the satellites as well as in the formation of the primaries, *but, because the process could go on at all, we have, I think, also additional evidence that there must have been a great amount of heat produced.* This heat is necessary to the hypothesis, both for the formation of the primary and the secondary bodies; because, unless you have heat enough to get perfect dissociation, you will not have that sorting out which always seems to follow the same law.

So much then for the passage from star to planet. Does this then throw any light upon the question—what I acknowledge to be one of the great points it is my duty to discuss—of the origin of the chemical constitution of the Earth?

Twice I have insisted upon this—that the hypothesis is almost worthless unless we assume very high temperatures. Now then, let us consider the Earth, which we know to be one of the interior planets, at the moment the ring—in which form it once existed according to the hypothesis—had been broken. By the breaking of this ring we have the future Earth, a mass of vapour in a state of incandescence.

I have already told you enough about the near similarity of the chemical constitution of the earth and sun to justify me in again asking you to let me see in the existing sun just such a mass of matter as our Earth then was. Now then, we simply go over the same line of facts again. This list of metals, with the exterior metalloids, must now do duty, not as it did before, for a nebula before it threw off its rings, but for our own Earth, after the time when a ring had formed to become the Moon ultimately. What would happen?

We know for certain that the Earth is now a cool body; but I do not think we know that with any greater certainty than we know that the Earth was once a very hot body; therefore

there has been a process of cooling going on. Now I want you to answer for yourselves this question, What would be the stages of the cooling? We have, by hypothesis, metalloids outside—metalloids not in combination with metals, in consequence of the high temperature. Such as the solar condition is now, such doubtless was the terrestrial condition then. What is the first process then that takes place on cooling?—combination. What then will be the process of combination? The metals and the metalloids will combine, according to their position in the present atmosphere of the sun, in the then atmosphere of the Earth. If, let us say, oxygen and chlorine cannot combine with hydrogen at a particular stage of temperature, they may go lower down, and attempt to combine with calcium and magnesium. But it is certain that if at any time they could have combined with magnesium and calcium, they would have had no chance of combining with iron, because iron was shielded by this enormous buffer of the upper metals. So that we ought to find that the crust of the Earth in the main consists of combinations of metalloids with those metals which exist highest in the atmosphere of the sun. Now it is not necessary that I should state any detailed facts on this point, because Professor Roscoe has already done that for me. I am sure you will all at once grasp that the composition required by the state of things I have pictured is exactly such a composition as Dr. Roscoe has brought before you; and if that is not sufficient I will read this extract from a work by an eminent geologist, Professor Prestwich. This is what he says about the composition of the Earth's crust:—

"The whole number of known elements composing the crust and atmosphere of the Earth amount only to sixty-four, and their relative distribution is vastly disproportionate. It has been estimated that oxygen in combination forms by weight one-half of the Earth's crust; silicon enters for a quarter; then follow aluminium, calcium, magnesium, potassium, sodium, iron, carbon. These nine together have been estimated to constitute $\frac{977}{1000}$ of the Earth's crust. The other $\frac{23}{1000}$ consist of the remaining fifty-five non-metallic and metallic elements."[1]

Now I think that I shall carry you with me when I say that an hypothesis like the one which I have brought before you

[1] Prestwich, *The Past and Future of Geology.* Macmillan, 1875.

—an hypothesis due to Kant and Laplace—which leads to mental results so very near the truth of nature, if it cannot be accepted as actual truth, is so near the truth that it deserves that any amount of trouble shall be brought to bear upon it to test it more and more carefully, to find out its weak points and to promulgate its strong ones, in order to beget thorough work.

You see, then that if the metalloids combine with this upper group of metals, two things happen—two points relative to the chemistry of the Earth, which are well worth further inquiry. It follows that a large mass of the interior of the Earth consists of pure metal—and as Dr. Roscoe has referred to that point I need not touch upon it further—and if the Earth is anything like the sun—and we have no reason to doubt their almost perfect similarity—we may be perfectly certain that a large portion of that metal will be iron. It is quite possible that the magnetic state of the Earth—for the Earth is a great magnet—may be connected with the existence of this enormous mass of perfectly pure iron low down in the Earth. I am not recalling your attention to the existence of this pure iron with any commercial view, but it is important that we should learn all we can in regard to the Earth's magnetism, upon which our commerce so largely depends.

Another point is this, if the history of the Earth and the history of the other planets, so far as the chemical nature of the crusts goes, is a history of the descent of the metalloids upon the metals, *we must regard the atmosphere of any planet at any time as the mere residuum which has been left after all possible combination has taken place.* Our own atmosphere consists of oxygen and nitrogen—still uncombined, fortunately—and of aqueous vapour, a combination of oxygen with the highest known metal which we see on the list.

This consideration at once explains how it is that in the moon—which at one time doubtless was the scene of activities of a geological character probably far greater than anything which took place here; that in the moon—of which I bring before you a very beautiful portrait by Mr. Rutherfurd, of New York—so far as we know, there is now no atmosphere at all; or, at all events, if any atmosphere exist there, it is one so slight that scarcely a remnant of the pure gases has been left, and no aqueous vapour.

This brings us to several very interesting questions regarding the Earth's future; but I feel that I shall not be justified in entering upon them. I trust, however, with regard to the past, that you will be content to see, in the facts that I have ventured to bring before you, that chemists really would be justified in giving great attention to the study of the chemical nature of non-terrestrial matter, in order that the true chemistry of the Earth may be better understood.

LONDON:
R. CLAY, SONS, AND TAYLOR, PRINTERS,
BREAD STREET HILL,
QUEEN VICTORIA STREET.

SCIENCE LECTURES
AT SOUTH KENSINGTON.

Crown 8vo., with Illustrations,
Price 6d. each.

PHOTOGRAPHY. By Captain ABNEY, R.E., F.R.S.

ABSORPTION OF LIGHT AND FLUORESCENCE. By Professor STOKES, F.R.S.

KINEMATIC MODELS. By Professor A. B. W. KENNEDY, C.E.

SOUND AND MUSIC. By Dr. W. H. STONE.

OUTLINES OF FIELD GEOLOGY. By Professor A. GEIKIE, F.R.S.

THE STEAM ENGINE. By F. J. BRAMWELL, C.E., F.R.S.

MACMILLAN AND CO., LONDON.